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PS 1 Learning from Experiences

Development of Economic and Environment-friendly 66kV Array Cable

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SUMMARY

After the continuous accumulation of offshore wind farm projects, the design of 66kV inter array cable is constantly updated and iterated. From the economic point of view: due to the traditional structure of copper core cable is expensive, for the sake of cost reduction, large cross-section aluminium core cable is used more and more, which greatly reduces the cost of the cable; from the perspective of environmental protection: due to the traditional structure of the submarine cable uses the lead sheath design, it will have a negative impact on the environment, then the design of copper wires with an aluminium plastic laminate is constantly replacing lead sheath to meet the increasing environmental protection requirements. This structural change has also led to the development of the cable structure from a dry design to a wet design, which puts forward more and higher requirements for the development of new-type water tree-resistant insulation materials; In terms of water blocking performance: due to the advancement of offshore wind farm projects to deep water, there have been considerations for the development of new seawater blocking tapes and water blocking glue for array cables; from the perspective of armor: due to the mechanical performance, armor loss, and armor cost. Comprehensive considerations lead to a variety of different armor options such as galvanized steel wire armor, stainless steel wire armor, and mixed steel wire armor (steel wires with PE wires). Due to the above reasons, the development of 66kV array cable needs to be fully verified and considered to design a 66kV array cable that is truly suitable for future offshore wind farm development.

KEYWORDS

3-core submarine cable, 66kV, inter array cable, offshore wind farm

1 INTRODUCTION

Due to the requirements of energy conservation, emission reduction, environmental protection and other aspects, the development and utilization of renewable energy has become the key development direction of the energy transition in the past decades. Among them, offshore wind power is an important part of renewable energy. For offshore wind power, the inter array cable used to connect wind turbines is a very important part.

Offshore wind farm inter array cable is a continuously iterative and updated product. After decades of development of offshore wind farm, more and more requirements have been put forward for reducing the project development cost. Therefore, most offshore wind projects are equipped with large-capacity wind turbines. This requires the rated voltage of the array cable to be increased from 33kV (or 35kV) to 66kV. Due to the rapid development of 66kV offshore wind inter array cables, IEC announced a new standard IEC63026-2019 for submarine cables. The application scope of this standard just meets the voltage level of 66kV inter array cables, which provides an important reference for our cable design [1].

However, IEC63026-2019 stipulates only the applicable performance and test requirements of the submarine cable, and does not specify the specific structure of the submarine cable. Therefore, we must consider both standards and project experience to design a 66kV array cable that is truly suitable for future offshore wind farm development.

2 CABLE DESIGN AND MANUFACTURE

A schematic drawing of the submarine power cable is shown in Figure 1. The inter array cable is a three core design combined with fibre optic cable elements and PE fillers.

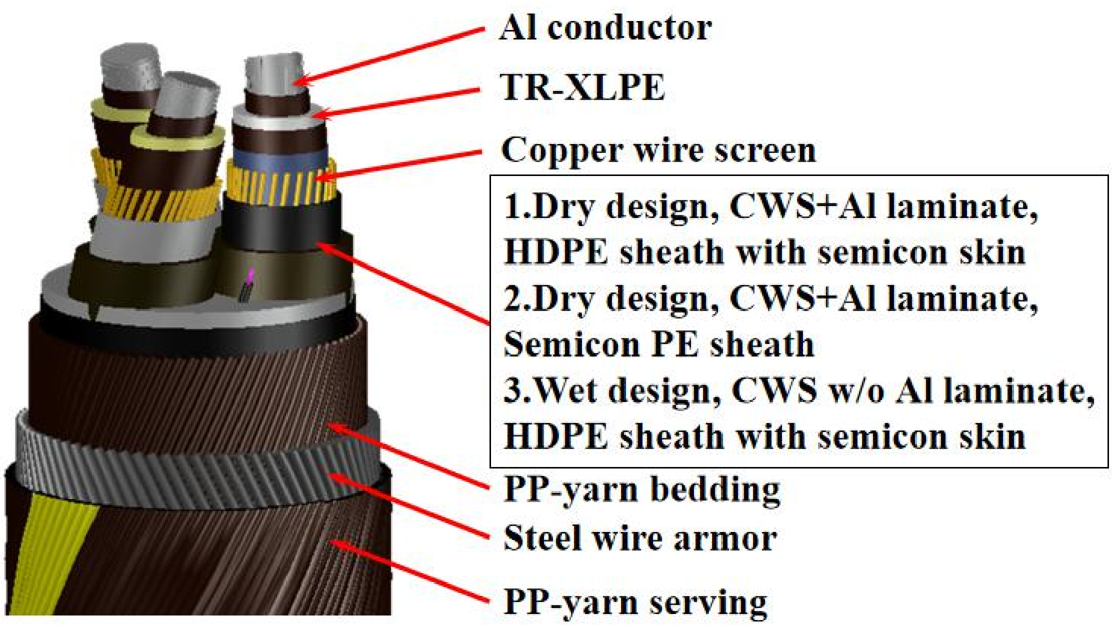

Figure 1 Schematic drawing of IAC design

Conductor

The conductors shall be a compacted circular design, constructed from plain hard draw aluminum wires and filled with a water blocking compound and/or water swellable tapes/yarns to prevent water propagation along the cable longitudinal direction in case of cable fault during operation which is qualified at a target water depth as per IEC or CIGRE standard. The conductor is designed according to the requirements of class 2 compacted and stranding type as per IEC 60228 [2].

Aluminum has lower conductivity compared to copper resulting in the need to select larger conductor cross sections. Despite the larger conductor cross section, cost reduction is achieved due to the lower material price of aluminum compared to copper.

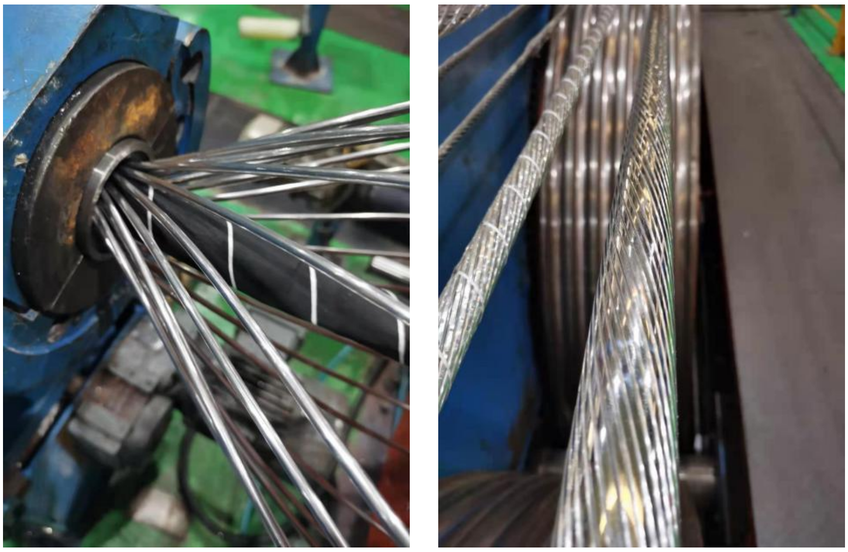

Figure 2 Al conductor stranding

Insulation system

The insulation system shall consist of an inner semi-conducting screen layer, the insulation compound and an outer semi-conducting insulation screen, extruded simultaneously (triple head extrusion) in order to avoid interlayer voids and contamination. The insulation is made of one layer of extruded cross-linked polyethylene (XLPE) compound with additional additives to improve the water tree resistant property which is compatible with the lead-free design comparing to common XLPE. The XLPE insulation can be produced either in CCV or VCV line. After the insulation is produced, degassing is applied to get rid of the cross-linking by-products to improve the insulation quality. Tests will be done to check the effectiveness of degassing. The insulation screen shall consist of black semi-conducting thermosetting material and shall be continuously bonded to the insulation. The insulation system shall meet up with the maximum conductor temperature according to the relevant IEC standard.

According IEC60840: 2020 '13.1 General and range of prequalification test approval', electrical prequalification tests are not required when [3]:
a) Maximum allowed electrical field strength at the conductor screen is <8 kV/mm
b) Maximum allowed electrical field strength at the core screen is <4 kV/mm
Therefore, the insulation thickness of the 66kV inter array cable is basically to meet the above requirements as thin as possible to reduce costs.

Figure 3 Troester triple extruder system

Metallic screen
Copper wires with equalizing copper tape are applied on the insulation core to provide the path for capacitive current during normal operation and short circuit current during short circuit condition. Water swelling tapes are also applied both under and over the copper wires to achieve required longitudinal water penetration resistant performance. Longitudinal colored strips (red, yellow, and blue) are applied under the water swelling tape as phase identification.

Radial moisture barrier & Core sheath
A longitudinal aluminium laminate foil bonded to polyethylene sheath is designed as moisture barrier, which could effectively avoid the direct contact between the insulation core and the surrounding water. The polyethylene sheath shall be extruded simultaneously to guarantee the bonding between the aluminium laminate foil and core sheath. In addition, semi-conductive polyethylene sheath is extruded over the polyethylene sheath to facilitate the voltage test on the polyethylene sheath after installation.
The design of copper wires with an aluminium plastic laminate is constantly replacing lead sheath to meet the growing environmental requirements.

There are 3 different cable designs for IAC:
1) Semi-dry design: Copper wires screen with Al plastic laminate, HDPE sheath with semiconductive skin
2) Semi-dry design: Copper wires screen with Al plastic laminate, semiconductive PE sheath
3) Wet design: Copper wires screen without Al plastic laminate, HDPE sheath with semiconductive skin

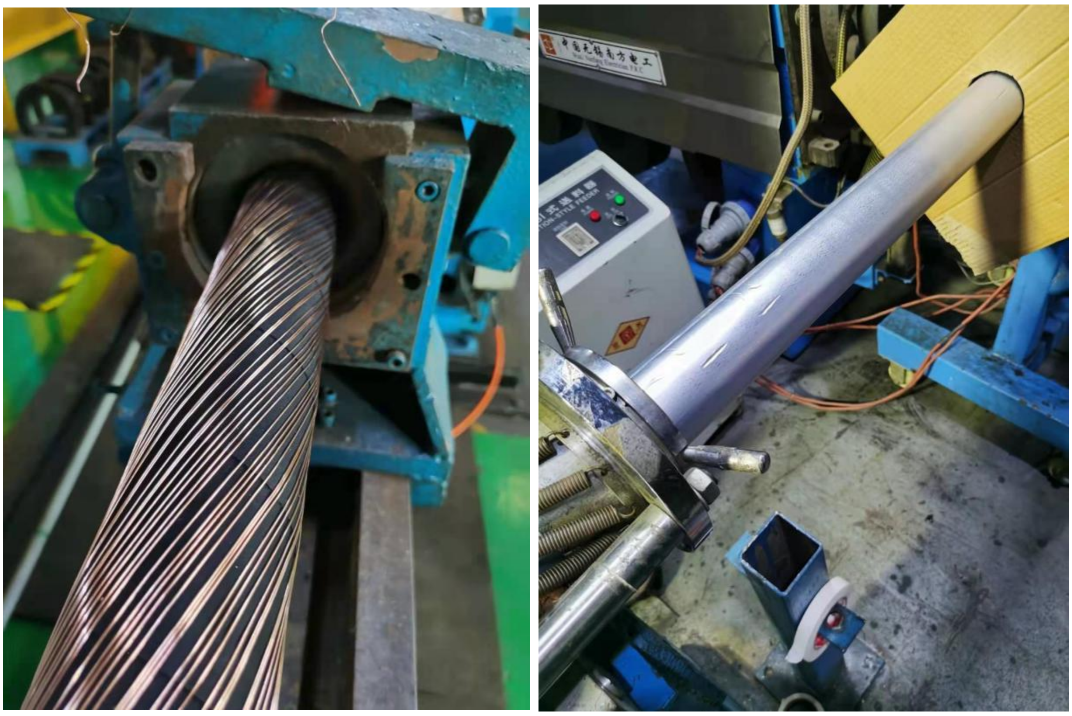

Figure 4 Copper wires screen and Al laminate

Laying-up and armouring

The three power cable cores and interstitial fiber optic unit(s) are laid-up together by a vertical laying up machine, which avoids the imposition of torsion stresses to the cores. The interstices are filled with suitable material to provide a substantially round shape after the laying-up. These fillers could be either pre-shaped fillers or PP yarn fillers according to the production process. The assembled cores will be tightened together with two binder tapes to prevent the displacement of each element.

The armour shall consist of a single layer of galvanized steel wires with a diameter not less than 5mm. This phase includes the armoring bedding, the armor and the outer serving applied in one single process. One layer of polypropylene yarns is applied over the assembly as bedding for the armor wires. An armor of galvanized wires is applied over this bedding.

Two layers of polypropylene strings are applied over the armor as cable serving, in order to provide a degree of abrasion protection and to reduce skid during cable loading and laying process.
The polypropylene serving is applied with pattern of a black and yellow strip in order to give high visibility to the cable and enable observation of cable movement.

The armour shall be designed to provide adequate strength and protection for the cable. The armour shall be designed and manufactured to ensure that bird caging of cable armour cannot occur during normal cable handling and installation operations. The armour shall be capable of withstanding the maximum permissible pulling forces of the cable during installation.

According IEC63026: 2019 Annex G ‘Tensile bending and tensile load calculation’, the tensile load used in the tensile bending and the tensile tests shall be chosen on the basis that the test tension is larger than the tensile force that will be experienced during all steps of the installation (and repair if applicable). So the maximum pulling tension at minimum bending radius of the designed IAC has to be larger than the calculated tension at maximum buried depth.

Figure 5 SKET Laying-up system

3 DEVELOPMENT

3.1 Factory flexible joint welding strength test

In order to ensure the mechanical properties of the aluminum factory flexible joint, we have carried out break tests before the type test. Based on our existing capabilities, we tried two different welding methods: V groove welding or welding layer by layer.

Then we used horizontal tensile machine to break three different aluminum conductors:

1) 2000mm2 Aluminum Conductor without welding joint
2) 2000mm2 Aluminum Conductor with joint welded layer by layer
3) 2000mm2 Aluminum Conductor with joint V groove welded

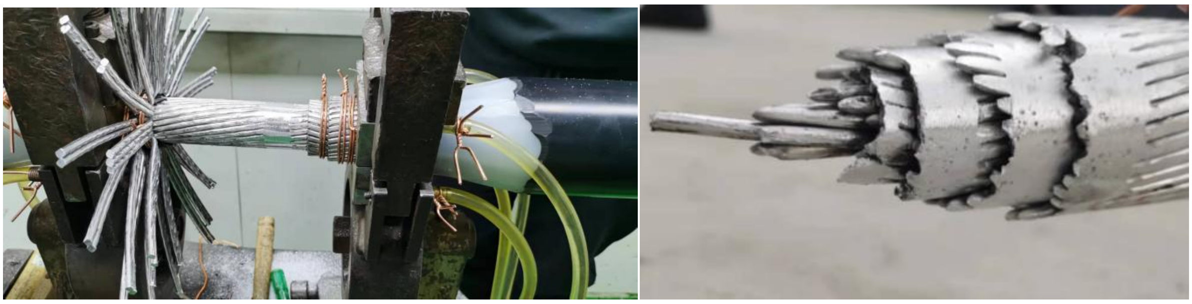

Figure 6 Aluminum conductor with joint welded layer by layer

Figure 7 Aluminum conductor with joint V groove welded

We can find that no matter what kind of welding method is used, the broken position is concentrated on the edge of the welding point. So in future development, we will focus on how to improve the strength of this position.

After the test, the breaking force of the conductor is as follows:

Table 1: Conductor break test

Conductor type	Average break force	Force Factor
2000mm2 Aluminum Conductor without welding joint	156.3kN	1
2000mm2 Aluminum Conductor with joint welded layer by layer	85.5kN	0.547
2000mm2 Aluminum Conductor with joint V groove welded	79.7kN	0.510

According to the breaking test, it can be concluded that the mechanical strength of welding layer by layer is slightly stronger than the V-groove welding, but a safety factor of 0.547 still needs to be considered relative to aluminum cable without joint.

So the welding layer by layer will be used for the factory flexible joint in 66kV type test.

3.2 Offshore flexible repair joint

Due to the high cost of installing a repair rigid joint and its lack of flexibility, the cable laying company begin to consider the offshore flexible repair joint. Usually the flexible joints are done at the factory, so there is no need to recover the armor. But for this joint, the recovery of the armour is a necessary process.

Figure 7 Flexible repair joint

4 TYPE TEST

A type test was performed on the 3×1200 mm² 38/66 (72.5) kV XLPE submarine power cable which was summarized above. The type test program was performed under consideration of IEC 63026:2019. The qualification of submarine power cables by the type test program recommended by IEC 63026:2019 is divided into four parts: mechanical tests, electrical type tests, longitudinal/radial water penetration test and non-electrical type tests.

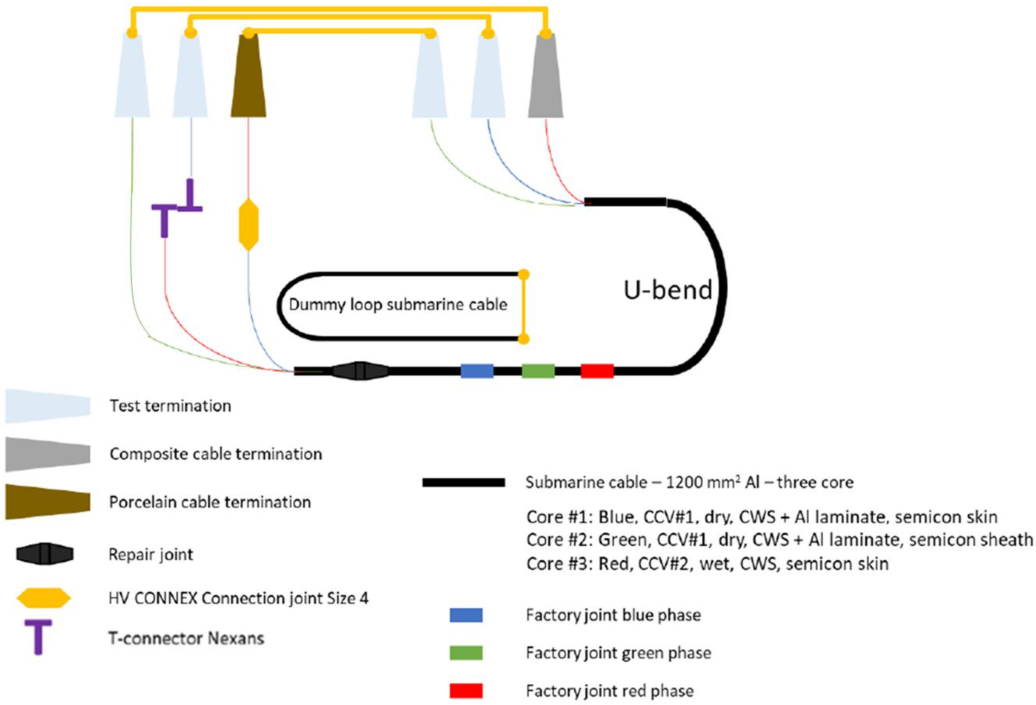

Figure 8 Type test loop

To qualify the cable to be produced in different production line(s), type test shall be performed on each planed production line(s). Three phases in the test loop will be made into three different metallic screen: Blue phase will be produced by CCV#1 with CWS+Al laminate, semicon skin; Green phase will be produced by CCV#1 with CWS+Al laminate, semicon sheath; Red phase will be produced by CCV#2 with CWS, semicon skin. If the type test passes, all three constructions will be verified, almost unprecedented.

4.1 Mechanical tests

During the mechanical type test mechanical loads acting on submarine power cables during handling, installation and operation are simulated.

Coiling test

Inter array cables are commonly stored in static tanks during the single production steps as well as for transportation and cable installation. The coiling test as part of the type test simulates the torsional load applied to a coiled cable and validates the coiling ability of IACs.

The 3x 1200 mm² 38/66 (72.5) kV XLPE submarine power cable was coiled into fixed static tanks after the stranding process as well as after the armoring process. A cable sample of about 400 m length was used for the coiling test. The test cable was wound from a drum and coiled into a static tank. Its end was fixed in the coiling core with a minimum of ten layers on the bottom of the static tank. After coiling, the cable shall be rewound onto the storage facility. The coiling and rewinding process was performed five times. The test coiling diameter is 8.5 m and drop height is 20.0m.

Figure 9 Coiling test of the 3x 1200 mm² 38/66 (72.5) kV XLPE submarine power cable into a fixed static tank

After the coiling test, samples for the following tensile bending test and electrical type test were extracted from the coiled sample.

Tensile bending test

The purpose of the tensile bending test is to simulate the resistance of the object to bending under tension typically caused by spooling to carrousel and passing the top chute during installation, pull in and recovery. It will verify the samples resistance to bending under tension without damage to its mechanical, hydraulic, optic and electrical properties.

Figure 10 Tensile bending test of the 3x 1200 mm² 38/66 (72.5) kV XLPE submarine power cable around a 6.0 m sheave

The test was performed on a 63 m long 3x 1200 mm² 38/66 (72.5) kV XLPE submarine power cable sample which was cut from the coiling test sample. Cable pulling heads were installed at both ends of cable samples. In the tension heads the 3 conductors and the armour wires were connected to the test set up. The tension in the 3 conductors was adjusted to a max. of 54 kN during the test.

Tensile test
The purpose of this test is to verify the performance of the cable and joints when exposed to an axial tensile force without bending. The tensile test shall be performed if a rigid joint is included in the cable system. A separate tensile test is not required, if the rigid joint is included in the tensile bending test but not passed around the wheel.

4.2 Electrical type tests
Samples for electrical type test shall be taken from the cable or cable system subjected to previous tensile bending tests and, if applicable, coiling tests as specified in IEC 63026: 2019 '12.4 mechanical tests'. Where applicable, the sample containing the rigid joint shall be subjected to the tensile test prior to the electrical type test. All electrical type test were performed according to the test parameters specified in IEC 63026: 2019.

4.3 Longitudinal/radial water penetration test
For submarine cables the water penetration tests are divided into three tests:
– LWP a: conductor longitudinal water penetration test (see IEC 63026 12.6.2), ;
– LWP b: metal screen longitudinal water penetration test (see IEC 63026 12.6.3);
– RWP: radial water penetration test of joints (see IEC 63026 12.6.4).
The tests have mechanical and thermal preconditioning as described below.
The mechanical preconditioning includes a tensile bending test and, if applicable, a coiling test before the tensile bending test.
The water used in the tests shall correspond to the application of the cable system and be either tap water in case the cable is installed in fresh water, or saltwater with a salinity of the specific area of the cable installation. If there is an absence of information concerning the application, then a concentration of 3,5 % by weight of NaCl shall be used.

4.4 Non-electrical type tests
The International Standard IEC 63026: 2019 specifies a non-electrical test sequence (see Table 1) on insulation, on the conductor and insulation screen as well as the outer sheath. During those test the different material qualities were analyzed by hot set test, shrinkage test, aging test, pressure test and purity test.

Table 2: Type test sequence

Description	Reference
Electrical test	
Partial discharge test at ambient and high temperature	IEC 63026 §12.5.3
Tan δ measurement	IEC 63026 §12.5.4
Heating cycle voltage test	IEC 63026 §12.5.5
Lightning impulse voltage test followed by a power frequency voltage test	IEC 63026 §12.5.6
Examination	IEC 63026 §12.5.7
Resistivity of the semi-conducting screens	IEC 63026 §12.5.8
Water penetration test	
Conductor water penetration test (longitudinal)	IEC 63026 §12.6.2
Metal screen water penetration test (longitudinal)	IEC 63026 §12.6.3
Radial water penetration for (factory, repair and field) joints	IEC 63026 §12.6.4
Non-electrical test	
Check of cable construction	IEC 63026 §10.4, 10.6, 10.7, 10.8, 10.9
Tests for determining the mechanical properties of insulation before and after ageing	IEC 63026 §12.7.3
Tests for determining the mechanical properties of non-metal sheaths before and after ageing	IEC 63026 §12.7.4
Ageing test on pieces of completed cable to check compatibility of materials	IEC 63026 §12.7.5
Pressure test at high temperature for ST7 oversheaths	IEC 63026 §12.7.6
Hot set test for XLPE insulation	IEC 63026 §12.7.8
Measurement of carbon black content of black PE oversheaths	IEC 63026 §12.7.9
Tests on components of cables with a longitudinally applied metal tape or foil, bonded to the over sheath	IEC 63026 §12.7.10
Water absorption test on insulation	IEC 63026 §12.7.11
Shrinkage test for XLPE insulation	IEC 63026 §12.7.12
Shrinkage test for PE oversheath	IEC 63026 §12.7.15

5 WET DIELECTRIC QUALIFICATION TEST

In case that the IAC is qualified as 'wet design', the cable supplier shall test the IAC insulation for wet applications in accordance to Cigre TB 722 [4].

Qualification of wet dielectrics comprises an accelerated ageing protocol on sufficiently representative cable samples followed by an assessment of the residual dielectric strength at the end of its design life. Three ageing protocol (Regime A-C) are provided for wet dielectric qualification test in Cigre TB 722 cl.3.6.3. Regime A is refer to cl.5.4.15 of HD 605 S2:2008[5] with saturating medium that is changed from potable water to saline and the applied voltage is calculated from rated voltage to E_{design}. We choose the Regime A which is at 50Hz or 60Hz and up to 8750h and 17500h duration.

Test conclusion: The cable core samples produced by Hengtong Submarine Power Cable Co., Ltd. Had complied with the requirements of wet dielectrics qualification test (Regime A) of Cigre TB 722: 2018.

6 CONCLUSION

Relying on the accumulative experience and issued IEC standards, we designed our own unique new 66kV array cable suitable for the future development trend of global offshore wind farm. In order to fully meet the transmission requirements of offshore wind farm, we designed one 1200mm^2 aluminium core cable for type testing to cover most application scenarios. The conductor adopts a new water blocking design with sea water blocking tape. According to the IEC63026-2019, this new design has passed the conductor water penetration test at a depth of 100 meters, which can meet the water depth requirements of most offshore wind farm projects. In order to carry out the design of environment-friendly metal sheath, we engaged a third-party testing agency conduct a 17500h wet dielectric qualification test (Regime A) according to the requirement of Cigre TB722, and the test was successfully completed, which ensures the diversity of metal sheath design and paves the way for the development of environment-friendly metal sheath. Considering the overall economy of the cable, we adopt a thinner insulation design, which reduces the cost of raw materials from the insulation to a certain extent. This design reduces the overall weight of the cable, which not only reduces the production cost, but also facilitates the transportation of 66kV array cable. With this design, the new economic and environment-friendly 66kV offshore wind array cable developed can fully meet the requirements of the global offshore wind power market in the future and provide a novel solution for the energy conservation and cost reduction of future offshore wind farm project.

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