D.5.7 Report electrical power cable characteristics

FULGOR (EL)

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FLOTANT -Innovative, low cost, low weight and safe floating wind technology optimized for deep water wind sites, has received funding from the European Union´s Horizon 2020 research and innovation programme
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Abstract

Floating Offshore Wind (FOW) turbines will require MV/HV dynamic power cables to interconnect arrays and to connect to the long length static export power cables, which transmit the power from the offshore substations to the onshore grid, highlighting the need for cable solutions with high performance and reliability, yet cost effective.

This deliverable will demonstrate the results of the mechanical and electrical testing which were performed at Hellenic cables' submarine plant (Fulgor). This test sequence was selected according to IEC 63026 Std. and Cigre Recommendations No.623 in order to validate the cable behavior during transportation, installation and operation. Fatigue testing was performed at University of Exeter and all relevant information is presented in D5.6 *"Report on mechanical power cable characteristics"*. In addition, a successful two-year aging test was performed on an insulated cable core in order to validate the operation of the wet design. The test results are presented in D5.8 *Report on insulated core testing after aging*".

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1 Introduction

Within the scope of FLOTANT Project was to develop, design, manufacture and test a light-weight and low cost dynamic cable solution for deep water floating wind applications. The cable sample, mentioned in here “first sample”, was manufactured at FULGOR plant, which is located in Sousaki, Corinth, Greece, and at RWTH Aachen Institute of Textile Technology. The main innovations of the manufactured cable design resulting in a cost effective, flexible and light-weight cable are as follows:

1. The cable core is of wet design subject to influence of water aging but eliminating the radial water penetration metal barrier over the power core, which is also subject to fatigue. Eliminating the metal barrier will reduce cost and will improve the cable’s fatigue life.
2. The conventional copper conductor has been replaced by aluminium, which is more cost effective for the same current rating, in order to study fatigue life of aluminium conductors in dynamic cable applications.
3. The conventional double steel wire armour was replaced by an innovative Carbon Fibre Reinforced Polymer (CFRP) braid with integrated Fibre Optic (FO) units to monitor the behaviour (strain & temperature) of the cable during fatigue testing.

Due to limitations on the continuous manufacturing length of the CFRP braid at ITA-RTWH, three 3m long demonstrators were manufactured. Therefore, due to the short length, the electrical and mechanical demonstration of performance testing could not be implemented on the first sample. Only the fatigue test was performed on one of the samples using the DMaC test rig by Exeter University.

Therefore, a decision has been made within the consortium and has been approved by the Project Officer to manufacture a second cable design with an innovative hybrid armouring at Fulgor premises, using existing industry submarine cable manufacturing equipment, permitting manufacture of longer cable lengths. The sample, mentioned in here “second sample” was manufactured of length suitable for all the mechanical and electrical testing.

In the next Chapter, a detailed description of the second sample design is presented. Finally, the results are illustrated through the attached official test report of the Hellenic Cables’ submarine plant (Fulgor, Quality control department).

2 Design and manufacturing of the second cable sample

Regarding the second cable sample, the only difference compared to the first cable sample is related to the armouring layer and the integrated fibre optic elements. Details concerning the manufacturing of the submarine power cores and the laying-up process can be found in the publicly available deliverable D3.4 "*Final 72.5kV dynamic cable sample*".

The conventional double steel wire armour was replaced by an innovative double wire armour consisting of two layers of synthetic wires helically applied in opposite directions to achieve torsional neutrality. The armouring round wires consist of synthetic braided rope made of Ultra-high molecular weight Polyethylene (UHMWPE) constantly retained by polyethylene jacket. Moreover, an outer polyethylene jacket with anti fishbite and anti biofouling additives was applied as an outer protective layer of the three-core submarine cable. A 3D rendered image of the 66 kV second cable design is illustrated below.

Figure 1. 3D rendered image of the 66 kV second cable

In addition, six (6) Fibre Optic (FO) units to monitor the behaviour (strain) of the cable during fatigue testing (replicating operational conditions) were integrated in the first innermost armouring layer by replacing synthetic armour wires respectively, spaced apart 60 deg. More particularly, each FO unit consists of one (1) optical fibre in the middle mechanically protected by aramid yarns and a layer of polyethylene jacket. A representative drawing of the FO unit design is presented below.

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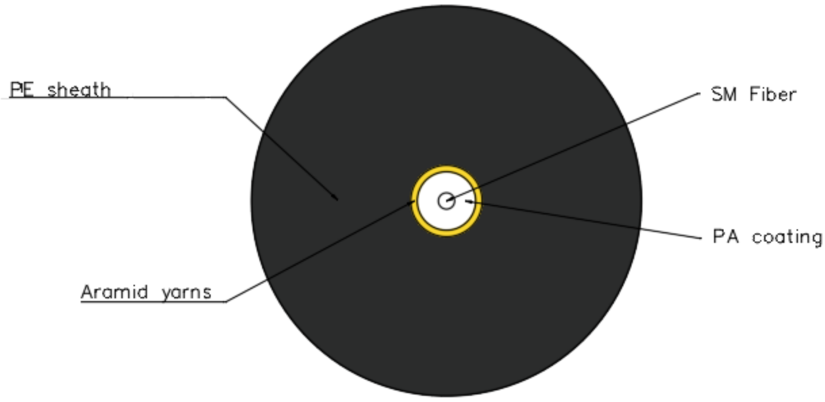

Figure 2. FO unit desing

Images illustrating the manufacturing of the armouring process and the storage on a drum can be found below.

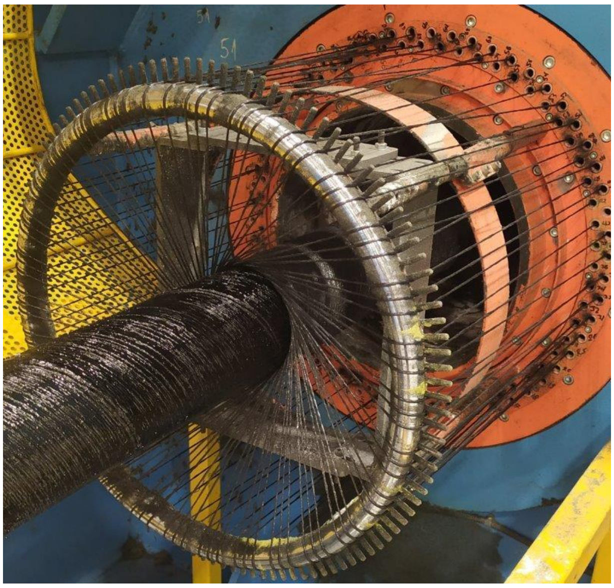

Figure 3. manufacturing of the armouring process

Figure 4. Cable storage

The three-core submarine cable was successfully subjected to mechanical and electrical tests at Fulgor premises and, a separate sample, to a fatigue test employing the DMaC test rig of Exeter University.

Both cable samples after fatigue testing were sent back to Fulgor. The electrical routine testing after the fatigue was not possible due to very short length. Therefore, they were subjected to visual inspection and no damage was observed (conductor, screen, armour, FO unit) due to fatigue. Moreover, the continuity of the conductors and the screens was also checked and no discontinuity was observed. In addition, the measurement of attenuation for the FO elements was not possible due to very short length but the continuity of the fibres was checked and no breakage was found.

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3 Test Report - Results

3.1 Purpose

The purpose of this document is to present an overview of the mechanical and electrical tests for the full scale 66 kV dynamic submarine cable to demonstrate satisfactory performance.
The following tests were performed by Hellenic Cables S.A. in FULGOR premises. The test sequence was based on CIGRE TB 623, CIGRE TB 490 and IEC 63026.

3.2 General description of test object

A description of the cable under investigation is presented below.

1. Dynamic Submarine Cable:

Type	3x240 mm^2 AL/XLPE/CTS/PE/PE/DWA/PE with 3xFO/SST/PE/SWA/PE
Rated voltage U_0/U	38/66 (72.5) kV
Standard specification	IEC 63026, IEC 60840 ed 5 (where applicable), CIGRE TB 490 and CIGRE TB 623
Manufacturer	FULGOR SA

3.3 Performed tests

All tests foreseen were carried out satisfactory and all measured values were compared with those data and values given by the above standard specifications and found to meet the requirements. The tests were performed between 24 November 2021 and 7 April 2022.

- **Mechanical tests:**
  - **Tensile bending test** according to IEC 63026 §12.4.2 to take into account the forces that apply to cables during laying and normal recovering
    - Drum diameter : 5.0 m
    - Applied tension: T ≥ 100kN
    - Number of passes: 3 times wind and unwind on the drum
    - Assessment after electrical test

Figure 5. Tensile bending test

- **Impact test** according to Cigre 623 §6.6 performed for information to establish the impact capacity of the cable and to give an indication of the effect of a typical impact.
  - Weight of the hammer: approx. 25 kg
  - Drop height of the hammer: 82 cm
  - Impact energy 201 J
  - o Visual inspection revealed no significant damage acc. to Cigre §5.1.4

Figure 6. Impact test

- **Crush test** according to Cigre 623 §6.3 to verify that the cable can withstand the expected crush loads during installation or repair.
  - Crush load ≥ 60 kN/m
  - Tension Force ≥ 100 kN/m
  - Duration of test = 1 h
  - o Visual inspection revealed no significant damage acc. to Cigre §5.1.4

- **Crush test for long term stacking** according to Cigre 623 §6.4 to verify that the cable can withstand long term crush loads representative for stacking during storage, transportation or operation.
  - Applied weight ≥ 40 kN/m
  - Duration of test ≥ 7 days
  - o Visual inspection revealed no significant damage acc. to Cigre §5.1.4

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Figure 7. Crush test for long term

Sequential electrical type tests according to IEC 63026 §12.5:

The tests were performed on a sample of the dynamic cable which was previously subjected to the tensile bending test and impact test.

- **Measurement of insulation thickness** according to IEC 63026 §12.5.1 & IEC 60811-201
  - Average insulation thickness < 105% of nominal insulation thickness
  - Therefore test voltage values according to IEC 63026 table 4 for the rated voltage of the cable.

- **Partial discharge test at ambient temperature** according to IEC 63026 §12.5.3 & IEC 60885-3
  - Sensitivity ≤ 5 pC
  - Test voltage: 62,3 kV after 10 seconds at 72 kV
  - No detectable discharge exceeding the sensitivity at 62,3 kV

- **Tanδ measurement** according to IEC 63026 §12.5.4
  - Test temperature: 95 – 100 °C
  - Test voltage: 36 kV
  - Tan δ < 10 x 10^{-4}

- **Heating cycle voltage test** according to IEC 63026 §12.5.5
  - 20 heating cycles
  - Heating duration: ≥8 hours, the conductor was maintained within 95 and 100ºC for at least 2 hours of each heating period
  - Cooling duration: ≥16 hours to a conductor temperature less than or equal to 30 °C or within 10 K of ambient temperature
  - Test voltage: 72 kV
    - Successfully completed, no breakdown of the insulation occurred

- **Partial discharge test at ambient temperature** according to IEC 63026 §12.5.3 & IEC 60885-3
  - Sensitivity ≤ 5 pC
  - Test voltage: 62,3 kV after 10 seconds at 72 kV
  - No detectable discharge exceeding the sensitivity at 62,3 kV

- **Partial discharge test at high temperature** according to IEC 63026 §12.5.3 & IEC 60885-3
  - Sensitivity ≤ 5 pC
  - Test temperature: 95 – 100 ºC. The conductor was maintained within temperature limits for more than 2 hours
  - Test voltage: 62,3 kV after 10 seconds at 72 kV
  - No detectable discharge exceeding the sensitivity at 62,3 kV

- **Lightning impulse voltage test** according to IEC 63026 §12.5.6 & IEC 60230
  - Test temperature: 95 – 100 ºC. The conductor was maintained within temperature limits for more than 2 hours.
  - Ligthning impulse test voltage: 10 positive and 10 negative at 325 kV
  - No breakdown of the insulation or flashover occurred.

- **Power frequency voltage test after the lightning impulse test** according to IEC 63026 §12.5.6
  - Test voltage: 90 kV AC
  - Test duration: 15 minutes
  - No breakdown of the insulation occurred.

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- **Examination** according to IEC 63026 §12.5.7.
    - Examination with normal vision revealed no
        - break, crossing or permanent bird caging of armour wires
        - harmful indentations in the cable cores
        - damage to the insulation
        - damage to the conductor

- **Non-Electrical tests** according to IEC 63026 §12.7:
- **Check of cable construction** according to IEC 63026 §12.7.2
    - The examination of the conductor and measurements of insulation, oversheath, metal screen, and armour were carried out and wre found to comply with the requirements
- **Tests for determining the mechanical properties of insulation before and after ageing** according to IEC 63026 §12.7.3
    - Without ageing:
        - Tensile strength ≥ 12.5 N/mm2
        - Elongation at break ≥ 200%
    - After ageing in air oven:
        - Air temperature = 135 ± 3 oC, Duration = 168 h
        - Variation of tensile strength ≤ ±25%
        - Variation of elongation at break ≤ ±25%
- **Tests for determining the mechanical properties of over sheaths of the power cores before and after ageing** according to IEC 63026 §12.7.4
    - Without ageing:
        - Tensile strength ≥ 12.5 N/mm2
        - Elongation at break ≥ 300%
    - After ageing in air oven:
        - Air temperature = 110 ± 2°C, Duration = 240 h
        - Elongation at break ≥ 300%
- **Ageing tests on pieces of complete cable to check compatibility of the materials of the power cores** according to IEC 63026 §12.7.5
    - Air temperature = 100 ± 2°C, Duration = 168 h
    - Insulation:
        - Variation of tensile strength ≤ ±25%
        - Variation of elongation at break ≤ ±25%
    - PE sheath:
        - Elongation at break ≥ 300%

- **Tests for determining the mechanical properties of SCPE oversheath of the FO cable before and after ageing** according to IEC 60811-401 and IEC 60811-501
  - Without ageing:
    - Tensile strength ≥ 12.5 N/mm2
    - Elongation at break ≥ 300%
  - After ageing in air oven:
  - Air temperature = 110 ± 2°C, Duration = 240 h
    - Elongation at break ≥ 300%

- **Ageing tests on pieces of complete cable to check compatibility of materials of the FO cables** according to IEC 60811-401 and IEC 60811-501
  - Air temperature = 100 ± 2°C, Duration = 168 h
    - Elongation at break ≥ 300%
- **Pressure test at high temperature on PE oversheaths of the power cores** according to IEC 63026 §12.7.6
  - Test temperature = 110 ± 2°C, Duration = 6 h
    - Indentation value ≤ 50%
- **Pressure test at high temperature on PE oversheath of the armoured FO cable** according to IEC 60811-508
  - Test temperature = 110 ± 2°C, Duration = 6 h
    - Indentation value ≤ 50%
- **Hot set test for XLPE insulation** according to IEC 63026 §12.7.8
  - Air temperature = 200 ± 3 oC, Time under load = 10 min, Mechanical stress = 20 N/cm2
    - Elongation under load (Max) = 175%
    - Permanent elongation after cooling (Max) = 15%
- **Water absorption test on insulation** according to IEC 63026 §12.7.11
  - Gravimetric method (according to IEC 60811-402)
    - Temperature 85 ± 2°C, Duration: 336 h
    - Increase of mass (max) = 1 mg/cm^2
- **Shrinkage test for XLPE insulation** according to IEC 63026 §12.7.12
  - Temperature = 130 ± 3°C, Duration = 1 h,
    - Permissible shrinkage (max) = 4.0%
- **Shrinkage test for PE sheath of the power core** according to IEC 63026 §12.7.15
  - Temperature = 80 ± 2°C, Duration = 5 h, Number of heating cycles= 5
    - Permissible shrinkage (max) = 3.0%

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- **Shrinkage test for PE oversheath on optical fiber cables** according to IEC 60811-503
  - Temperature = 80 ± 2°C, Duration = 5 h, Number of heating cycles= 5
    - Permissible shrinkage (max) = 3.0%
- **Thermogravimetric test for insulating, profile fillers and non-metallic sheathing materials** according to HD 605 S2:2008 § 2.5.7
  - **Water penetration tests**:
  - **Conductor longitudinal water penetration test** αccording to IEC 63026 § 12.6.2
    - Water pressure Pr_{water} = 10 bar for 10 days
      - No water presence at the distance of 17.5 m
  - **Metal screen longitudinal water penetration test** according to IEC 63026 §12.6.3
    - Water pressure Prwater = 3 bar for 10 days
      - No water presence at the distance of 23 m
  - **Longitudinal water penetration test of optical fibre unit** according to IEC 63026 §12.6.2 where applicable
    - Water pressure Prwater = 10 bar for 10 days
      - No water presence at the distance of 17.5m

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4 Conclusions

This work has offered a summary of the design and the manufacturing of the second sample with a double wire synthetic armouring. Moreover, the successful results of all the mechanical and electrical testing validate that the proposed cable design can withstand mechanical and electrical conditions during transportation, installation and operation. The outcome of this deliverable in combination with the results from the fatigue testing (D5.6) and the aging test (D5.8) are evaluated as encouraging and promising towards the development of light weight and low cost dynamic cable solutions at commercial scale.