PETROBRAS	**TECHNICAL SPECIFICATION**	Nº: I-ET-3000.00-1500-700-PEK-004	
	CLIENT: PETROBRAS		FOLHA: 1 de 16
	JOB: Subsea Processing and Boosting Systems		
	AREA: Subsea Electrical Power System		
SUB/ES/EECE	TITLE: **HIGH-VOLTAGE ELECTRICAL POWER CABLE FOR SUBSEA UMBILICAL**		SUB/ES/EECE/ECE

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR AFFECTED SHEETS
0	Original Emission

Note 1: Revised by CLW4, U3FL, DVLY, RHCG, CSMP, CJME, UPOV

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	08/05/2023								
DESIGN	SP&BS								
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SUMMARY

1 PURPOSE

1.1 This Technical Specification (TS) defines the minimum requirements for design, qualification, manufacture, testing and acceptance of HIGH-VOLTAGE ELECTRICAL POWER CABLE ELEMENT from 3.6/6.0(7.2)kV up to 18/30(36)kV and its accessories for use as part of static and dynamic umbilical for subsea application.

1.2 This TS is part of a document package for Subsea Processing and Boosting Systems (SP&BS) bid and product development purposes.

1.2.1 This TS shall be referred in full for Subsea Electrical Power System (SEPS) detail design, umbilical design data, umbilical's intended application, and its topside and subsea interfaces.

2 TERMS, DEFINITIONS, ACRONYMS AND ABREVIATIONS

2.1 For the purposes of this TS, the following Acronyms and Abbreviations apply.

EPR: Ethylene Propylene Rubber

HEPR: Hard grade Ethylene Propylene Rubber

HV: High-Voltage (voltages equal or greater than 1kV)

RMS: Root Mean Square

SEPS: Subsea Electrical Power System

TDR: Time Domain Reflectometry

TS: Technical Specification

U_0: Phase-to-earth voltage.

U: Phase-to-phase voltage in a balanced three-phase system ($U = \sqrt{3}\ U_0$)

U_m: $U_m = 2\ U_0$

3 REFERENCE DOCUMENTS

3.1 PETROBRAS' Documents

Doc. Nr.	Title
[1] SEPS Technical Specification NOTE 01	Subsea Electrical Power System
[2] I-ET-3000.00-1500-700-PEK-002	Subsea High-Voltage Power Connection System
[3] I-ET-3000.00-1500-29B-PAZ-006	Qualification of the Subsea Umbilicals
[4] I-ET-3000.00-1519-29B-PZ9-003	Subsea Umbilical Systems
[5] ET-3000.00-1500-600-PEK-010	Mechanical Requirements for Umbilical Termination Assemblies - UTAs
[6] Interface with FPSO Technical Specification NOTE 01	Interface of the SP&BS with the FPSO facilities

NOTE 01: Technical Specification specific of the bidding process.

3.2 Industry Codes, Standards, Rules and Regulations

The latest issue of the reference standards shall be used unless it is specified in the table below or otherwise agreed. Other recognized standards may be used, provided it can be shown that they meet or exceed the requirements of the standards referenced below. Variations or alternatives, if proposed, shall be submitted to PETROBRAS for approval before umbilical Detailed Design starts.

Doc. Nr. or Author	Title
[7] IEC 60228	Conductors of insulated cables
[8] IEC 60502-2	Power cables with extruded insulation and their accessories for rated voltages from 1kV (U_m = 1,2kV) up to 30kV (U_m = 36kV) – Part 2: Cables for rated voltages from 6kV (U_m = 7,2kV) up to 30kV (U_m = 36kV)
[9] IEC 62095	Electric cables – Calculations for current ratings – Finite element method
[10] ISO 13628-5	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 5: Subsea umbilicals
[11] CIGRE TB 722	Recommendations for additional testing for submarine cables from 6kV (U_m = 7,2kV) up to 60kV (U_m = 72,5 kV)

4 GENERAL REQUIREMENTS

4.1 Each single-core cable shall be rated according to [8] rated voltages.

4.2 Each single-core cable shall be composed, at least, of conductor, conductor screen, insulation, insulation screen, individual metallic layer, and polymeric outer sheath according to [8].

4.3 Each conductor shall be of annealed, stranded copper conductors, class 2, according to [7].

4.3.1 Conductor cross-section shall be defined considering maximum conductor temperature of 80ºC when carrying maximum operational current and at 60ºC maximum air temperature, as per [9].

4.3.2 Maximum conductor cross-section is limited to 630mm^2. Only one cable per phase is allowed.

4.3.3 SUPPLIER shall perform a Finite Element Analysis according to [9] of the proposed subsea umbilical and HV power cable configuration imposing maximum operational current and frequency to validate conductor maximum temperature of 80ºC. Finite Element Analysis Report shall be presented in the first SEPS technical meeting as per [1].

4.4 The conductors shall be longitudinally sealed to prevent water penetration (between the wires) along each single-core cable in case of umbilical (cable) severance. The sealing material must be thermally and chemically compatible with all other materials in the umbilical. SUPPLIER shall state in the Qualification Assurance Report, item 11 of this TS, the designed technical characteristics related to the water penetration prevention, explaining how this requirement is addressed.

4.5 Two water blocking bedding layers shall be applied, respectively, between the insulation screen and the single-core cable metallic layer, and between the single core cable metallic layer and the single-core cable outer sheath. SUPPLIER shall state in the Qualification Assurance Report, item 11 of this TS, the designed technical characteristics related to these two mechanical barriers, explaining how this requirement is addressed.

4.6 Single-core cable shall have a non-metallic conductor screen consisting of an extruded semi-conducting compound, which may be applied on top of a semi-conducting tape. The extruded semiconducting compound shall be firmly bonded to the insulation.

4.7 Single-core cable insulation shall be constituted by an extruded and vulcanized polymeric compound (EPR or HEPR), designed according to its rated voltage. The insulation shall be rated for a maximum conductor temperature of no less than 90ºC during normal operation (maximum current and 60ºC ambient temperature as per [3] and no less than 250ºC for five (5) seconds with maximum short-circuit current flowing. Besides stating the material used and maximum rated temperature, SUPPLIER shall include in the Qualification Assurance Report, item 11 of this TS, the nominal thickness according to [8].

4.8 The insulation screen shall be composed of an outer semi-conductive layer plus a metallic layer:

4.8.1 The outer semi-conductive layer shall be manufactured by a semi-conductive compound extruded directly over the insulation. The outer semi-conductive layer shall be extruded simultaneously with the conductor semi-conductive screen and with the insulation in a triple-extrusion process.

4.8.2 The metallic layer over the outer semi-conductive layer shall be constituted by a braid of soft temper thinned copper wires. Such metallic layer shall be designed to conduct short-circuit currents without damages.

4.9 The sheath around each single-core cable shall be of a thermoplastic material that shall not degrade the quality of other materials with which it may be in contact in the lay-up. The single-core cable outer sheath shall be designed so that the insulated power conductors are capable to operate in a fully flooded environment inside the umbilical. The sheath thickness and physical properties shall be suitably selected to not compress the inner single-core cable layers due to shrinkage after extrusion. Also, extruded layers which are designed to assure water tightness in the whole length of the cable and at the interface between the single-core cable and its connector, to assure such property, shall have their circularity controlled during manufacturing process. SUPPLIER shall state in the Qualification Assurance Report, item 11 of this TS, how the single-core cable design and manufacture procedures and/or process accomplish the above features.

4.10 The single-core cable shall be designed and manufactured in such a way that fusion between polymeric layers and between insulation and copper core is avoided. SUPPLIER shall state in the Qualification Assurance Report, item 11 of this TS, how the cable design and manufacture procedures and/or process accomplish this feature.

4.11 Each single-core cable shall be easily identified by means of either color strips, sequential numbers, or color coding (more than one type of marking is desired). Single-core cable markings shall be stable under all environmental conditions for storage, handling and operation during the specified service life and shall not impair its insulation.

4.12 Fillers, if used in contact with a single-core cable, shall be of polymeric material and not cause or suffer chemical or mechanical degradation of any other material of the cable.

4.13 The three-phase configuration, either using one or more than one single-core cable per

phase, shall comply with the following grounding premises:

4.13.1 The copper metallic layer (metallic shield) over the insulation of single-core cables shall be effectively earthed at both ends (subsea end termination and platform end termination).

4.13.2 SUPPLIER shall specify all technical characteristics of the grounding system design and technical data related to the expected/calculated short-circuit currents; maximum short-circuit current peak and RMS values (three-phase, phase-to-phase, phase-to-phase-to-ground and phase-to-ground) and respective duration time; continuous short-circuit current phase-to-ground; protective devices, induced current, etc. according to electrical studies in [1].

4.14 The single-core cable and the three-phase configuration shall be provided with adequate mechanical strength to protect it against the effects of mechanical loads generated during manufacturing, handling, installation, operation, and retrieval, expected during the umbilical specified service life and according to [3] and [4].

4.15 The single-core cable and the three-phase configuration functional characteristics shall be assured by SUPPLIER during umbilical manufacturing, storage, transportation, handling, subsea installation, testing, operation, and retrieval, during the specified umbilical service life and according to [3] and [4].

4.16 Materials to be used in the single-core cable and the three-phase configuration and in its accessories shall withstand the aging and degradation effects due to ambient conditions during the specified service life. It includes, among others, agents such as sea water and marine growth, as well as UV radiation when the cable extremities are subjected to long term sun radiation during umbilical storage at a non-protected area or during operation (i.e., pigtails connected to platform riser balcony junction box).

4.17 Steel wires for armoring, if used in the three-phase configuration bundle, shall not degrade with corrosion. SUPPLIER shall be asked at any moment prior to the final delivery of the umbilical to make accelerated corrosion tests to demonstrate that mechanical strength of the armor wires will be compatible with the service life specified. SUPPLIER shall present to PETROBRAS approval a report on the necessity (or not) of anti-corrosive treatment of cable armoring, if used, prior to the cable manufacture.

4.18 The single-core cable and the three-phase configuration minimum bending radius shall be

compatible with the dimensions of accessories such as pull-in heads and Deployment Bases for which the cable may be stored during deployment, as per [3] and [4] or abandonment in the seabed.

4.19 SUPPLIER has total responsibility over the single-core cable and the three-phase configuration qualification, manufacturing, and testing, even when the single-core cable and the three-phase configuration itself and its qualification, manufacturing and testing is provided by SUPPLIER sub-contractors.

5 SINGLE-CORE CABLE SPLICES

5.1 SUPPLIER shall present the qualification program of a field splice for the proposed single-core cable as per section 10.5 of this TS in the first SEPS technical meeting.

5.2 If the length of the umbilical requires the use of splices, each single-core cable shall be connected by qualified splices as per section 10.5 of this TS and located inside diametrical joints or splice boxes according to the umbilical mechanical specifications in [4].

5.3 SUPPLIER shall provide the splicing service as part of the umbilical installation, including in the umbilical scope of supply the qualified personnel, tools and materials required for each splice. The onshore and offshore field splice technique shall be qualified by SUPPLIER for the required umbilical water depth, as per section 10.5 of this TS.

5.4 SUPPLIER shall include in the qualification program of a field splice, at least:

5.4.1 A detailed splice design (including material specification to be used, dimensions etc.).

5.4.2 Detailed procedure to manufacture such splices.

6 TERMINATIONS AND ACCESSORIES

6.1 Suitable protection caps to prevent water ingress in the single-core cable shall be supplied for the possibility that the single-core cable is not terminated during the pull-in operation and the umbilical needs to be laid down on the seabed.

6.2 For the umbilical subsea termination, each single-core cable shall be fitted with an electrical power connector, penetrator or crossover, according to [2] and [5].

6.3 For the umbilical topside termination, the three-phase configuration shall be fitted in a topside junction box, complying with [1] and [6].

7 MANUFACTURING REQUIREMENTS

7.1 In addition to the requirements found in the applicable ISO, API and IEC presented in section 0 of this TS and those adopted by the single-core cable supplier, SUPPLIER shall assure the traceability of materials used in cable construction as well as of all manufacturing records.

7.2 For manufacturing, the maximum diameter variation of the single-core cable extruded layers shall be defined in such way that the water tightness in the single-core cable interface termination is assured, as applicable. The external diameter and thickness of extruded layers shall be continuously monitored and recorded lengthwise during manufacturing, or a Spark Test shall be performed according to [10].

8 SINGLE-CORE CABLE AND THREE-PHASE CONFIGURATION DATASHEET

8.1 SUPPLIER shall present in the first SEPS technical meeting the designed or estimated data listed below, as a minimum. Standards and/or calculation methods used to estimate data shall be informed.

8.1.1 Single-Core Cable Datasheet:

8.1.1.1 Single-core cable supplier

8.1.1.2 Cross section with each layer thickness and tolerances and material description, as per section 4.9 of this TS.

8.1.1.3 Rated voltage (U_0/U(U_m)).

8.1.1.4 Insulation material information as per section 4.7 of this TS.

8.1.1.5 Minimum bending radius.

8.1.1.6 Velocity of propagation (VOP).

8.1.1.7 Electrical DC resistance at ambient temperature (Ohm/Km).

8.1.1.8 Temperature Coefficient of Resistance.

8.1.1.9 Electrical DC resistance at 90ºC (Ohm/Km).

8.1.1.10 Electrical AC resistance at 90ºC on 60Hz (Ohm/Km).

8.1.1.11 Capacitive reactance on 60Hz (uF/Km).

8.1.1.12 Inductive reactance on 60Hz (mH/Km).

8.1.1.13 Maximum Current Capacity x Ambient Temperature Curve, for ambient temperatures varying from 4ºC to 60ºC in air without solar radiation, highlighting the following temperatures: 4ºC, 25ºC, 40ºC, 55ºC and 60ºC.

8.1.1.14 Water ingress barrier technical design to fulfill sections 4.4 and 4.5 of this TS.

8.1.1.15 Single-core cable design, manufacture procedure and facilities to fulfill 4.9 and 4.10 of this TS.

8.1.1.16 Axial strength in kN.

8.1.1.17 Weight in air in kg/km.

8.1.1.18 Weight in seawater in kg/km.

8.1.2 Three-phase configuration Datasheet:

8.1.2.1 Cross section with distances and tolerances between each single-core cable in trefoil configuration.

8.1.2.2 Minimum bending radius.

8.1.2.3 Fillers' material, if used.

8.1.2.4 Electrical parameters with shield grounded at only one end:

8.1.2.4.1 Electrical AC resistance (Ohm/km), capacitive (uF/Km) and inductive (mH/Km) reactance at 90ºC conductor temperature on frequency range from 10Hz to 1500Hz.

8.1.2.4.2 Maximum Current Capacity x Ambient Temperature Curve, for ambient temperatures varying from 4ºC to 60ºC in air without solar radiation, highlighting the following temperatures: 4ºC, 25ºC, 40ºC, 55ºC and 60ºC.

8.1.2.5 Electrical parameters with shield grounded at both ends:

8.1.2.5.1 Electrical AC resistance (Ohm/km), capacitive (uF/Km) and inductive

(mH/Km) reactance at 90ºC conductor temperature on frequency range from 10Hz to 1500Hz.

8.1.2.5.2 Maximum Current Capacity x Ambient Temperature Curve, for ambient temperatures varying from 4ºC to 60ºC in air without solar radiation, highlighting the following temperatures: 4ºC, 25ºC, 40ºC, 55ºC and 60ºC.

8.1.2.6 Maximum voltage drop at SEPS' rated point of operation.

9 GENERAL TEST REQUIREMENTS

9.1 The HIGH-VOLTAGE ELECTRICAL POWER CABLE ELEMENT and its accessories shall be subjected to the qualification tests hereafter specified prior to the umbilical manufacture.

9.1.1 A detailed qualification scope and qualification schedule for each cable, splice and its accessories shall be presented in the first SEPS technical meeting, as stated [1].

9.1.2 The qualification program shall start immediately after the first SEPS technical meeting, as stated in [1].

9.1.3 Cable and accessories manufacturing shall begin only after all element qualification program is completed, with each element successfully qualified and the Qualification Assurance Report, as per item 11 of this TS, approved by PETROBRAS.

9.2 The HIGH-VOLTAGE ELECTRICAL POWER CABLE ELEMENT FAT shall be performed after the manufacturing of the electrical cable.

9.3 SUPPLIER shall provide adequate monitoring points during testing.

9.4 Unless otherwise specified, the acceptance criteria for the tests in this TS shall be those given in the reference standards.

9.5 In addition to SUPPLIER's own inspection and testing requirements, SUPPLIER shall perform the inspections and tests presented in sections 10 and 11 of this TS.

9.6 As a general directive, the electrical and mechanical characteristics of the HIGH-VOLTAGE ELECTRICAL POWER CABLE ELEMENT and its accessories to be tested shall be checked and documented before, during and after the mechanical resistance and hydrostatic pressure tests, whenever it is applicable.

9.7 Test results registered during test execution shall be scanned and an electronic copy send to PETROBRAS the day after test execution.

10 QUALIFICATION TESTS

10.1 HV Electrical Power Cable qualification shall be part of Umbilical Qualification Program as per [3].

10.2 At least 3 (three) samples of single-core cable shall pass through qualification tests.

10.3 The qualification tests shall comply, at least, with IEC 60502-2 tests listed below. Tests 10.3.1 up to and including 10.3.8 shall be applied successively to the same sample:

10.3.1 Electrical resistance of conductors.

10.3.2 Partial discharge test.

10.3.3 Bending test followed by a partial discharge test.

10.3.4 Tan δ measurement.

10.3.5 Heating cycle test followed by a partial discharge test.

10.3.6 Impulse test followed by a voltage test.

10.3.7 Voltage test for 4 hours.

10.3.8 Hydrostatic Pressure Test, as per section 10.4 of this TS.

10.3.9 Resistivity of semi-conducting screens.

10.3.10 Measurement of thickness of insulation.

10.3.11 Measurement of thickness of non-metallic sheaths (including extruded separation sheaths but excluding inner coverings).

10.3.12 Tests for determining the mechanical properties of insulation before and after ageing.

10.3.13 Tests for determining the mechanical properties of non-metallic sheaths before and after ageing.

10.3.14 Additional ageing test on pieces of completed cables.

10.3.15 Pressure test at high temperature on insulations and non-metallic sheaths.

10.3.16 Ozone resistance test for EPR and HEPR insulations.

10.3.17 Hot set test for EPR and HEPR insulations and elastomeric sheaths.

10.3.18 Oil immersion test for elastomeric sheaths.

10.3.19 Water absorption test on insulation.

10.3.20 Measurement of carbon black content of black PE oversheaths.

10.3.21 Determination of hardness of HEPR insulation.

10.3.22 Determination of the elastic modulus of HEPR insulation.

10.3.23 Shrinkage test for PE oversheaths.

10.3.24 Strippability test for insulation screen.

10.3.25 Water penetration test.

10.4 Hydrostatic Pressure Test:

10.4.1 At least 3 (three) samples of the cable under qualification shall be subjected to a pressure equivalent to 1.1 times the umbilical specified maximum water depth for at least 24 hours.

10.4.2 Routine tests according to [8] shall be performed before and just after the hydrostatic pressure test.

10.4.3 The test bench shall include a hyperbaric chamber with instrumentation to record the internal pressure and temperature. A fluorescent fluid shall be used to allow the identification of water ingress inside the samples.

10.4.4 At the end, the sample must be dissected and no mechanical damages, layers shrinkage and/or water ingress shall be observed. Samples' dissection shall be performed during the first 24 hours after the samples leave the hyperbaric chamber.

10.5 Single-Core Cable Splices:

10.5.1 At least 3 (three) samples of each cable splice shall pass through qualification tests. These samples shall be prepared according to the written procedure and have their mechanical strength validated by a test to verify the specified design breaking load of the spliced single-core cable.

10.5.2 Single-core cable splice shall be rated with the same rated voltage as and shall have the same layers of the single-core cable.

10.5.3 Each sample of spliced single-core cable shall pass through the qualification tests listed in section 10.3 from 10.3.1 to 10.3.8 of this TS.

10.6 Abandonment Cap:

10.6.1 At least 3 (three) samples shall be tested in hyperbaric chamber filled with fluorescent liquid at 1.1 times the pressure equivalent to the umbilical specified maximum water depth during at least 24 hours, then the cap shall be removed, and the cable stripped for visual inspection of signs of the fluorescent liquid ingress into the electrical cable.

10.7 Water treeing test of insulation material shall be performed according to [11].

10.7.1 If water treeing test of the insulation material has been already performed according to [15], SUPPLIER shall present the test report in the first SEPS technical meeting.

11 QUALIFICATION ASSURANCE REPORT

11.1 SUPPLIER shall include in the HIGH-VOLTAGE ELECTRICAL POWER CABLE ELEMENT Qualification Assurance Report the designed and the validated data through the qualification program listed below, as a minimum. Standards and/or calculation methods used to not direct measured data shall be informed.

11.1.1 Updated Single-Core Cable Datasheet according to item 8.1.1 of this TS:

11.1.2 Single-Core Cable Qualification Program, detailed test procedures and reports, as per section 10 of this TS and with description of qualification test facilities used.

11.1.3 Single-Core Cable Splice Qualification Program, detailed test procedures and reports, as per sections 5.4 and 10.5 and with description of qualification test facilities used.

12 FACTORY ACCEPTANCE TESTS (FAT)

12.1 HIGH-VOLTAGE ELECTRICAL POWER CABLE ELEMENT FAT shall comply, at least, with Routine and Sample Tests according to [8] and with Hydrostatic Test as per section 10.4 of this TS. Sample tests shall be performed in 3 (three) samples. FAT tests shall be as following:

12.1.1 Complete single-core cable:

12.1.1.1 Measurement of the electrical resistance of conductors.

12.1.1.2 Partial Discharge Test.

12.1.1.3 Voltage Test.

12.1.2 Three samples of single-core cable:

12.1.2.1 Conductor Examination.

12.1.2.2 Check of dimensions.

12.1.2.3 Voltage Test.

12.1.2.4 Hot Set for EPR or HEPR.

12.1.2.5 Hydrostatic Test.

12.2 SUPPLIER shall include in FAT Final Report the detailed test procedures and reports performed with the description of test facilities used.

12.3 6 samples, 1 meter long each, of the single-core cable used in umbilical manufacturing shall be delivered to PETROBRAS.

13 FACTORY ACCEPTANCE TESTS – COMPLETE UMBILICAL

13.1 Complete umbilical shall comply with [4].

13.2 The FAT of the HV Electrical Power Cable integrated in the complete umbilical shall comply, at least, with Routine Tests according to [8].

13.3 SUPPLIER shall update the three-phase configuration Cable Datasheet according to item 8.1.2 of this TS.

13.4 A TDR signature of the cable after complete umbilical manufacturing shall be performed and all TDR parameters and signal waveforms shall be part of the Umbilical Databook.

14 FIELD ACCEPTANCE TESTS – INSTALLED UMBILICAL

14.1 Insulation Resistance and Electrical Resistance Tests shall be performed after umbilical installation. SUPPLIER shall submit for PETROBRAS approval tests procedures and acceptance criteria, at least 45 (forty-five) days in advance prior to the scheduled start of the tests.

14.2 A TDR signature of the cable after installation shall be performed and all TDR parameters and signal waveforms shall be part of the Umbilical As-Laid Report.

15 UMBILICAL DATABOOK

15.1 SUPPLIER shall provide the As Built (measured) parameters listed in 8 in the Umbilical Databook (except the Maximum Current Capacity x Ambient Temperature Curve).

15.2 The Umbilical Databook shall include all qualification tests, FAT, and field test reports.