

	TECHNICAL SPECIFICATION		Nº: I-ET-3000.00-1500-700-PEK-007							
	CLIENT:		PETROBRAS					FOLHA: 1 de 26		
	JOB:		Subsea Processing and Boosting Systems							
	AREA:		Subsea Electrical Power System							
SUB/ES/EESUB		TÍTULO:		SUBSEA ELECTRICAL POWER SYSTEM						
									SUB/ES/EESUB/EPB	
INDEX OF REVISIONS										
REV.	DESCRIPTION AND/OR AFFECTED SHEETS									
0	Original Emission									
	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H	
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EXECUTION	CXS2									
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1

INTRODUCTION

1.1

The Subsea Electrical Power System (SEPS) designed by SUPPLIER shall comply with the following specific Technical Specifications (TS):

1.1.1

Interface with FPSO Technical Specification as per reference [1];

1.1.2

Subsea Processing and Boosting System (SP&BS) Technical Specification as per reference [2];

1.1.3

Material Requisition (RM) as per reference [3];

1.1.4

Subsea equipment document list (LD) as per reference [4].

1.2

SEPS designed by SUPPLIER shall comply with the following general requirements:

1.2.1

SEPS maximum rated point of operation to be considered in all detailed design activities shall be the maximum operational shaft power of the subsea pump it is driven.

1.2.2

SEPS total losses shall be limited so that the total active power delivered and active power demand at topside shall not be higher than specified in [1] at any subsea pump point of operation.

1.2.3

A Subsea HV Electrical Motor designed with, at least, 10% margin over its maximum operational shaft power in all subsea pump operational speed range. Motor design, manufacture, and test as a unit before its integration in the subsea pumping element shall be according to [5].

1.2.4

Use of single-phase penetrators and single-phase wet-mate (WM) connectors. Penetrators and WM connectors' phase-to-phase insulation voltage shall be designed with, at least, 10% margin over its maximum operational phase-to-phase voltage. Penetrators and WM connectors rated current at *in situ* ambient condition shall be designed with, at least, 20% margin over its maximum operational current at *in situ* ambient condition. Additionally, Subsea High-Voltage Power Connection System (HV-PCS) shall be according to [6].

1.2.5

High-Voltage Electrical Power Cable for Subsea Umbilical shall be EPR or HEPR insulated and designed with phase-to-phase insulation system with, at least, 10% margin over its maximum operational phase-to-phase voltage. Conductor maximum

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temperature shall be limited to 80°C at maximum operational current. Additionally, its design and qualification shall be according to [7], [10] and [11].

1.2.6 Topside High-Voltage Variable Frequency Drive (VFD) shall be according to [8].

1.3 Other specific system and equipment requirements are presented on section 4 of this TS.

2 PURPOSE

2.1 This TS defines the minimum requirements that shall be considered by SUPPLIER and that applies to all and each life cycle of the project, from SEPS Detail Design to Operation of the Subsea Boosting and Processing System (SB&PS) Project.

2.2 This TS is part of a document package and shall be referred in full for SP&BS Project detailed design and interfaces.

3 TERMS, DEFINITIONS, ACRONYMS AND ABBREVIATIONS

3.1 For the purposes of this TS, the following Terms and Definitions apply.

In situ ambient condition: temperature, pressure, and all fluids that equipment is in contact with, internally and externally, when in subsea operation.

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

DPIEF: Define, Plan, Implement, Evaluate, Feedback

LD: List of documents

EPR: Ethylene Propylene Rubber

FMECA: Failure Modes, Effects, and Criticality Analysis

FPSO: Floating, Production, Storage and Offloading

HAZID: Hazard Identification

HAZOP: Hazard and Operability Study

HEPR: Hard grade Ethylene Propylene Rubber

HMI: Human Machine Interface

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

HV-PCS: Subsea High-Voltage Power Connection System

IM-FMECA: Integrity Management Failure Modes, Effects, and Criticality Analysis

IP Code: Degree of Protection according to [21]

IR: Insulation Resistance

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ITMM: Inspection, Testing, Monitoring, and Maintenance
 ITP: Inspection and Test Plan
 JB: Junction Box
 MATIC: Manufacture, Assembly, Testing, Installation, and Commissioning
 P-FMECA: Process Failure Modes, Effects, and Criticality Analysis
 QA: Quality Assurance
 QC: Quality Control
 RAM: Reliability, Availability, and Maintainability
 RIAD: Reliability and Integrity Assurance Document
 RIM: Reliability and Integrity Management
 RBD: Reliability Block Diagram
 RM: Material Requisition with technical aspects and scope specific to the project
 SCADA: Supervisory Control and Data Acquisition
 SEPS: Subsea Electrical Power System
 SIT: System Integration Test
 SP&BS: Subsea Processing and Boosting System
 SUPPLIER: Company directly awarded by PETROBRAS responsible for the complete scope of supply and related activities. SUPPLIER may award sub-suppliers to deliver part of the scope of work maintaining responsibility over sub-suppliers' scope.
 TRAR: Technical Risk Assurance Review
 TRC: Technical Risk Categorization
 TRL: Technology Readiness Level
 TS: Technical Specification
 UTA: Umbilical Termination Assembly
 VFD: Variable Frequency Drive
 WM: Wet-Mateable

4 REFERENCE DOCUMENTS

4.1 PETROBRAS' Documents

Doc. Nr.	Title
[1] SP&BS INTERFACE WITH FPSO	Specific per project
[2] SP&BS Technical Specification	Specific per project
[3] SP&BS Subsea Equipment Material Requisition	Specific per project
[4] SP&BS Subsea Equipment Document List	Specific per project

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[5] I-ET-3000.00-1500-700-PEK-001	Subsea High-Voltage Electrical Motor
[6] I-ET-3000.00-1500-700-PEK-002	Subsea High-Voltage Power Connection System
[7] I-ET-3000.00-1500-700-PEK-004	High-Voltage Electrical Power Cable for Subsea Umbilical
[8] I-ET-3000.00-1500-700-PEK-006	Topside High-Voltage Variable Frequency Drive
[9] I-ET-3000.00-1500-600-PEK-010	Mechanical Requirements for Umbilical Termination Assemblies - UTAs
[10] I-ET-3000.00-1500-29B-PAZ-006	Qualification of the Subsea Umbilicals
[11] I-ET-3000.00-1519-29B-PZ9-003	Subsea Umbilical Systems

4.2 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.

Doc. Nr. or Author	Title
[12] API RP 17N, 2 nd Ed., Addendum 1 – May 2018	Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management
[13] API RP 17Q	Recommended Practice on Subsea Equipment Qualification
[14] IEC 60034-1	Rotating electrical machines – Part 1: Rating and performance
[15] IEC 60073	Basic and safety principles for man-machine interface, marking and identification – Coding principles for indicators and actuators
[16] IEC 60079-0	Explosive atmosphere – Part 0: Equipment – General requirements
[17] IEC 60079-1	Explosive atmosphere – Part 1: Equipment protection by flameproof enclosures “d”
[18] IEC 60079-7	Explosive atmosphere – Part 7: Equipment protection by increased safety “e”
[19] IEC 60092-502	Electrical installations in ships – Part 02: Tankers – Special features
[20] IEC 60447	Basic and safety principles for man-machine interface, marking and identification – Actuating principles
[21] IEC 60529	Degrees of protection provided by enclosures (IP Code)
[22] IEC 60533	Electrical and electronic installations in ships – Electromagnetic compatibility (EMC) – Ships with a metallic hull
[23] IEC 61892-2	Mobile and fixed offshore units – Electrical installations – Part 2: System design
[24] IEC 61892-3	Mobile and fixed offshore units – Electrical installations – Part 3: Equipment

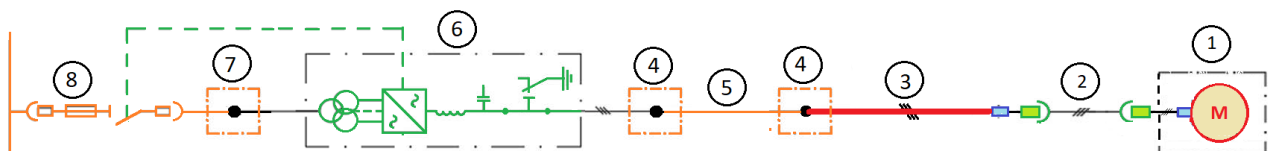
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[25] IEC 61892-6	Mobile and fixed offshore units - Electrical installations - Part 6: Installation
[26] IEC 61892-7	Mobile and fixed offshore units – Electrical installations – Part 7: Hazardous areas
[27] IEEE 519	Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
[28] IEEE Std. 3002.2	Recommended Practice for Conducting Load-Flow Studies and Analysis of Industrial and Commercial Power Systems
[29] IEEE Std. 3002.3	Recommended Practice for Conducting Short-Circuit Studies and Analysis of Industrial and Commercial Power Systems
[30] IEEE Std. 3002.7	Recommended Practice for Conducting Motor-Starting Studies and Analysis of Industrial and Commercial Power Systems
[31] IEEE Std. 3002.8	Recommended Practice for Conducting Harmonic Studies and Analysis of Industrial and Commercial Power Systems
[32] IEEE Std. 3004.8	Recommended Practice for Motor Protection in Industrial and Commercial Power Systems
[33] IEEE 3006 Series	Power System Reliability
[34] IEEE 3007 Series	Power System Maintenance, Operations, and Safety
[35] INMETRO 179/2010	Portaria 179 do Instituto Nacional de Metrologia, Normalização e Qualidade Industrial - INMETRO
[36] NR-10	Norma Regulamentadora 10: Segurança em Instalações e Serviços em Eletricidade
[37] NR-17	Norma Regulamentadora 17: Ergonomia
[38] ISO 14224, 3rd Ed., 2016	Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment
[39] ISA-5.06.01	Functional Requirements Documentation for Control Software Applications
[40] ISA-5.5	Graphic Symbols for Process Displays
[41] ISA-101.01	Human Machine Interfaces for Process Automation Systems

5 SEPS TOPOLOGY

5.1 SUPPLIER SEPS' topology shall be according to schematics presented in Figure 5.1 – a system with topside VFD, without topside step-up and subsea step-down transformers and with transmission voltage the same as the subsea motor voltage level, where:

Figure 5.1 – SEPS single line diagram

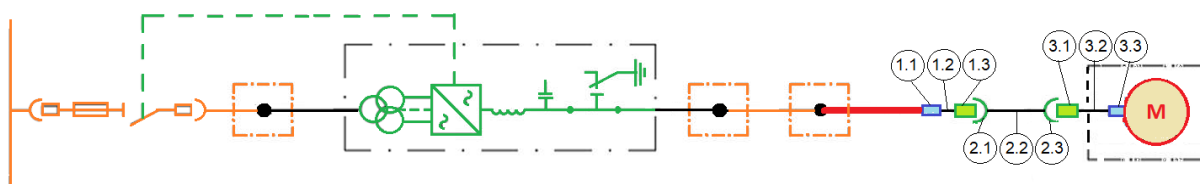


- 5.1.1 ① indicates the Subsea HV Electrical Motor that drives the Subsea Raw Water Injection Pump part of SUPPLIER' scope of supply and that shall be designed according to [5].
- 5.1.2 ② indicates the HV-PCS between umbilical termination and Subsea HV Electrical Motor. The HV-PCS is part of SUPPLIER' scope of supply and shall be designed according to [6].
- 5.1.3 ③ indicates the HV Electrical Power Cable for Subsea Integrated Umbilical part of SUPPLIER' scope of supply and that shall be designed according to [7]. Umbilical shall be according to [10] and [11], and UTA shall be according to [9].
- 5.1.4 ④ indicates the HV-JB to be installed at the Riser Balcony of the FPSO and near the Topsides Module. These HV-JB is part of SUPPLIER' scope of supply and shall be designed according to section 7.7 of this TS.
- 5.1.5 ⑤ indicates the 3-phase armored power cables, provided by FPSO as per [1], to transmit power from the Topsides Module HV-JB to the Riser Balcony HV-JB.
- 5.1.6 ⑥ indicates the Topsides HV VFD part of SUPPLIER' scope of supply and that shall be designed according to [8].
- 5.1.7 ⑦ indicates the HV power cables terminated in a HV-JB provided by FPSO as per [1].
- 5.1.8 ⑧ indicates the HV Circuit Breaker provided by FPSO as per [1].

6 HV-PCS DEFINITION

- 6.1 The main elements in SUPPLIER's scope of supply shall be according to schematics presented in Figure 6.1, where:

Figure 6.1 – HV-PCS main elements



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6.1.1 Each umbilical single-core HV Electrical Power cable, as per [7], subsea termination, pigtail and half WM connector, items 1.1, 1.2 and 1.3 in Figure 6.1 respectively, assembled inside UTA, as per [9]. 6.1.2 Each single-phase HV jumper ended in both extremities with half WM connectors to connect UTA to Subsea HV Electrical Motor, items 2.1, 2.2, and 2.3 in Figure 6.1 respectively, to be installed and connected subsea, as per [6]. 6.1.3 Each Subsea HV Electrical Motor penetrator, pigtail and half WM connector, items 3.3, 3.2 and 3.1 in Figure 6.1 respectively, assembled as part of the Subsea Pump retrievable module, as per [5], [6] and Erro! Fonte de referência não encontrada.. 6.2 In addition to the HV-PCS main elements described in item 6.1 of this TS, SUPPLIER shall supply all HV-PCS accessories needed to perform tests at surface and subsea, for protection and for intervention support, consisting, as a minimum, of: 6.2.1 Surface test connectors to perform IR test and electrical continuity check in all equipment (UTA and Subsea HV Electrical Motor) and HV jumpers individually and prior to system integration. 6.2.2 Subsea HV dummy connectors to perform IR and electrical continuity test in all equipment and HV jumpers as part of troubleshooting activities to effectively locate the point of failure in the SEPS. 6.2.3 Subsea parking places to allow parking of HV jumpers and subsea HV dummy connectors in adequate number to minimize subsea operations. 6.3 Surface protection caps. 6.4 Subsea protection caps. 6.5 HV jumpers' deployment frame to install HV jumpers separately and independently of other equipment installation, as per [6]. 6.6 SUPPLIER shall provide all special tools and tools' related accessories as part of its scope of work to perform HV-PCS foreseen activities to assembly, test, install, connect, and disconnect, troubleshoot, retrieve and repair HV jumpers, UTA and Subsea Pump retrievable module.			

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6.6.1 SUPPLIER shall present a list of these special tools at the first SEPS´ technical meeting.

7 SEPS DESIGN REQUIREMENTS

7.1 SUPPLIER´s designed SEPS shall be capable of carrying, in continuous service, the rated power and the power levels in all operational range defined by SUPPLIER to comply with all operational conditions detailed by SUPPLIER to fully fulfill SP&BS Project safety and performance requirements within equipment operational temperature, pressure, current and voltage limits and respective operational safety margins.

7.1.1 Operational phase-to-phase voltage shall not exceed 90% of equipment insulation voltage.

7.1.2 Operational current shall not exceed 80% HV-PCS rated current in subsea *in situ* ambient conditions.

7.1.3 Unless otherwise specified, hot spot temperature in any material due to the ambient temperature plus the additional Joule effect heating produced in rated condition shall not exceed 90% of material temperature limit.

7.2 SUPPLIER shall perform, at least, the following electrical studies to confirm safety and performance requirements are fulfilled:

7.2.1 Load Flow at different points of operation, e.g., maximum power, maximum voltage, maximum current, minimum and maximum frequencies, as per [28].

7.2.2 Short-Circuit in each node of the SEPS, as per [29].

7.2.3 Subsea motor starting, as per [30].

7.2.4 Harmonic analysis, as per [31].

7.2.5 Electromagnetic compatibility evaluation according to [22].

7.2.6 Protection coordination and selectivity, as per [32].

7.2.7 Arc fault incident energy calculation.

7.2.8 Grounding fault analysis in each node of the SEPS.

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7.2.9 SEPS transient analysis due to main input power loss (e.g., FPSO blackout or loss of permissive signal).

7.2.10 Earthing philosophy analysis.

7.2.11 Electrical insulation coordination study.

7.3 SEPS Total Harmonic Distortion shall comply with [27] not exceeding 5%. Individual components shall be limited to 3% distortion at worst operational condition regarding harmonic distortion.

7.3.1 A minimum of 36-pulse rectifier shall be selected.

7.4 Earthing system and earth fault detection shall comply with [23]. An earth fault shall be instantaneously isolated.

7.4.1 Topside HV VFD Drive shall provide an isolated or high-impedance earthing system in its output.

7.5 All equipment in SUPPLIER scope of supply shall have, at least, a TRL 4, according to [13], and a TRC C for equipment and procedure, according to [12].

7.5.1 The above TRL and TRC classification does not apply to the High-Voltage Electrical Power Cable for Subsea Umbilical.

7.6 The Topside HV VFD part of SUPPLIER’s scope of supply shall be installed in a Topside Module also provided by SUPPLIER, as per [1]. The Topside HV VFD and the Topside Module shall comply with the following requirements:

7.6.1 Topside Module shall be designed and provided according to [1] and completely installed and commissioned at the FPSO in the shipyard.

7.6.2 Electrical equipment shall comply with [24], [36] and [37].

7.6.3 Electrical equipment shall be manufactured with durable, non-hygroscopic and, at least, flame retardant materials. Materials used shall not degrade its characteristics due to offshore ambient conditions, e.g., humidity, salinity, platform movements and inclinations.

7.6.4 Ergonomic aspects shall comply with [15] and [20] and shall be observed during Detail

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Design to facilitate operation and maintenance and to reduce risks related to human factors during operation, inspection, and maintenance during all SEPS life cycle.

7.6.5 Electrical equipment with access to its internals from its rear part shall have the rear part access clearly identified with the same TAG and/or equipment name as used in equipment frontal part.

7.6.6 Electrical equipment enclosures and metallic parts shall be effectively bonded according to [19] and [25].

7.6.7 Electrical equipment installed inside the Topside Module shall have the minimum enclosure IP according to [21] as follows:

7.6.7.1 IP21 for transformers

7.6.7.2 IP22 for panels

7.6.7.3 IP34 for lighting fixtures

7.6.7.4 IP44 for accessories, junction boxes, switches, and sockets outlets.

7.7 HV-JB in SUPPLIER scope of supply shall comply with the following requirements:

7.7.1 HV-JB shall be suitable for operation in hazardous area classified Zone 2, Group IIA, Class T3 according to [16].

7.7.2 HV-JB shall comply with [35].

7.7.3 HV-JB protection shall be “Ex e” (Increased Safety) according to [18] according to [17].

7.7.4 The degree of protection provided by the HV-JB enclosure shall be IP56 or IP66 according to [21].

7.7.5 HV-JB enclosures and metallic parts shall be effectively bonded according to [19], [25] and [26].

7.7.6 Three 3-phase armored power cables, in parallel configuration, shall be connected at HV-JB, as per [1].

7.7.7 The HV-JB internal space, layout and insulated cable connections and components

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shall be compatible with umbilical and topside electrical power cable specifications. Each phase connection inside the HV-JB shall be easily identified with the same identification used in each single core cable.

7.7.8 The HV-JB shall allow disconnection and reconnection of topside and umbilical power cables maintaining its protection type (Ex) and degree of protection (IP). The HV-JB shall allow the performance of insulation resistance measurements of each of these cables when disconnected. The supplier shall provide procedures for safety disconnection and reconnection of topside and umbilical cables.

7.7.9 SUPPLIER shall perform a Fit Test of the HV-JB to be installed at the FPSO Riser Balcony with similar topside and umbilical cables and representative restrictions in cables pigtail length and Riser Balcony available space interferences to validate the detailed procedure to be used by SUPPLIER to perform the topside umbilical termination activity.

7.8 SUPPLIER shall provide SEPS Workstations. A local and a remote station for monitoring and control of the power system and its equipment; and a local and a remote second station for engineering and maintenance.

7.8.1 The architecture of supervisory control and security system, as well as the respective functional specification of SCADA, workstation and HMI shall be defined in a specific document.

7.8.2 The document package for control and instrumentation software according to [39].

7.8.3 At least, the following documents shall be provided: TAG list instruments, interlock matrix, cause and effect diagram, network topology, control/instrumentation overall wiring diagram, system architecture and interfaces and user manual.

7.8.4 SEPS' workstations may be the same BMS workstations provided that additional screens are dedicated for SEPS. SEPS screens shall be submitted for PETROBRAS approval.

7.8.5 The symbols of HMI according to [40].

7.8.6 HMI design shall consider operation and maintenance, including aspects related to ergonomics and human factors, according to [41]

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7.9 SUPPLIER is responsible to perform all connections between the SP&BS Topside scope of supply and the FPSO as part of topside installation and pre-commissioning activities, as per [1].

8 SEPS RISK ASSESSMENT

8.1 SUPPLIER shall implement a RIM process to assess and prioritize efforts based on the level and source of technical risks and uncertainties of the designed SEPS configuration and manage them as part of the project activities.

8.1.1 [12] shall be used as reference to RIM process.

8.1.2 [33] shall be used as reference to SEPS reliability analysis.

8.1.3 [34] shall be used as reference to SEPS maintenance, operations, and safety.

8.1.4 SUPPLIER shall perform biweekly SEPS’ follow-up technical meetings with PETROBRAS’ representatives using a web-based on-line meeting, conferencing, and videoconferencing tool.

8.1.5 The first SEPS technical meeting shall be schedule two weeks after purchase order placement. SUPPLIER shall present the whole project schedule with focus on SEPS related activities, SEPS configuration and equipment main data and the RIM process at this first SEPS’ technical meeting.

8.1.6 The further SEPS’ technical meetings shall cover all technical activities related to SEPS and its equipment performed during the last two weeks prior to the meeting and the planned activities during the next six weeks.

8.1.7 Each SEPS’ equipment that has qualification tests to be performed shall have its qualification program started immediately after SEPS second meeting and equipment manufacturing shall begin only after equipment qualification program is completed and the equipment successfully qualified. A detailed qualification schedule for each equipment under this circumstance shall be presented in first SEPS technical meeting and be updated for presentation at next SEPS technical meetings.

8.1.8 Qualification and Manufacturing ITP shall be presented in the first SEPS technical meeting.

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8.2 The RIM process shall cover all stages of the SEPS life cycle, from Detail Design to Operation, and related technical documents, analysis, and activities.

8.3 Risk assessment engineering techniques shall be able to clearly identify the impact of technical risks and uncertainties in SEPS’ Operational Safety and Production Efficiency and treat them adequately.

8.4 SEPS configuration designed by SUPPLIER shall meet, at least, the following goals and requirements:

8.4.1 Operational Safety: To design and elaborate procedures considering multifactor techniques to prevent any accident during manufacturing, testing, installation, commissioning, operation, intervention, and maintenance activities.

8.4.2 Production Efficiency: To specify, manufacture, test components and establish maintenance strategies to minimize unplanned system unavailability.

8.5 The RIM DPIEF assurance loop shall have its focus adjusted at the beginning of each project stage in accordance to [12] and as per sections 9, 10 and 11 of this TS.

8.6 RIM process shall provide adequate evidence that goals and requirements stated in sections 5, 6, 7 and 8.4 of this TS were correctly addressed and treated during project development.

8.7 A TRC shall be performed at the beginning and reviewed at the end of each project life cycle stage.

8.7.1 At least, the change risk factors for equipment and procedure in Annex A of [12] shall be considered.

8.7.2 A scorecard shall be generated for each equipment or procedure evaluated TRC A, TRC B or TRC C with information of all technical risks and uncertainties identified, the correspondent criticality to SEPS Requirements, Operational Safety and Production Efficiency, and the strategy to reduce risk to adequate levels in accordance to the goals and requirements as per sections 5, 6, 7 and 8.4 of this TS.

8.8 SUPPLIER shall perform a FMECA of each equipment or procedure evaluated TRC A, TRC B or TRC C.

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8.8.1 SUPPLIER shall develop/update an equipment hierarchy or taxonomy that is a realistic representation of the installed system in preparation for FMECA. SUPPLIER should consider item A.2.6.5 of [38] as reference.

8.8.2 The focus and the scope of the FMECA shall be adjusted to the object under analysis and the stage and timing of FMECA application.

8.9 Risk analysis of the complete SEPS configuration shall be performed through all project development to identify potential hazards and problems that may represent risks to personnel, equipment, or environment.

8.9.1 Hazards and risks related to each SEPS life cycle stage shall be identified.

8.9.2 The risk analysis procedure shall consider, at least:

8.9.2.1 Latest SEPS electrical studies, as per section 7.2 of this TS.

8.9.2.2 Latest equipment TS and datasheet.

8.9.2.3 Previously performed risk analysis reports.

8.9.2.4 List of historical accidents and failures in similar systems and with similar equipment.

8.9.2.5 FMECA results as per section 8.8 of this TS.

8.9.2.6 Failure modes stated in applicable industry codes, standards, rules, regulations, and recommended practices, considering [38] as one of the references.

8.9.2.7 System layout, interfaces, adjacent areas, and external causes.

8.9.2.8 Procedures, equipment, or other conditions that could contribute to human failure.

8.9.2.9 Management of changes performed since last risk analysis evaluation.

8.9.2.10 Identification of all related documents in its updated revision.

8.9.2.11 Identification of hazards and classification of risks.

8.9.2.12 Identification of existing safeguards and its suitability.

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8.9.2.13 Identification of actions and new safeguards that will eliminate, reduce, prevent, or mitigate the risk or hazard.

8.9.3 The risk analysis shall be performed by a multidisciplinary team to ensure rigor and completeness. At least, appropriate technical specialists with adequate knowledge of the following areas shall participate in the risk analysis:

8.9.3.1 Detail Design.

8.9.3.2 Topside and Subsea Operation and Intervention.

8.9.3.3 Topside and Subsea Maintenance and Inspection.

8.9.3.4 Instrumentation and Control.

8.9.3.5 Environment.

8.9.3.6 Human Factors.

8.9.3.7 Applicable industry codes, standards, rules, regulations, and recommended practices.

8.10 SUPPLIER shall perform a RAM analysis of the normal operation mode of the complete SEPS configuration.

8.10.1 The RAM analysis shall cover the complete SEPS life cycle.

8.10.2 The scope and the battery limits of the analysis shall include all SEPS´ topside and subsea equipment needed for SP&BS Project normal operation and within SUPPLIER´ scope of supply.

8.10.3 FMECA results as per section 8.8 of this TS shall be used as input data in RAM analysis.

8.10.4 SUPPLIER shall present a list of each equipment modelled for RAM analysis, its functional requirements, failure modes and associated failure rates considered in the analysis.

8.10.5 SUPPLIER shall present a list of all resources considered in the RAM analysis, with indication of mobilization time and intervention time used in each type of intervention.

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Additionally, assumptions on spare parts availability and vessel availability considered in the mobilization and intervention times shall be clearly stated.

8.10.6 SUPPLIER shall clearly present all the assumptions considered in the RAM modeling.

8.10.7 SUPPLIER shall present the RBD in all modelling levels considered in the RAM analysis.

8.10.8 Simulation results shall give, at least, the average availability with the 90%, 50% and 10% probability of exceedance values.

8.11 A TRAR shall be scheduled at the end of each project stage and before moving to the next project stage.

8.11.1 At least, considerations in Annex B, section B.6 of [12] shall be addressed.

8.12 SUPPLIER shall review and update the SEPS RIAD at the end of each project life cycle stage.

8.12.1 At least, considerations in Annex B, section B.6 of [12] shall be addressed.

9 SEPS DETAIL DESIGN

9.1 At Detail Design stage, SUPPLIER’S RIM process shall be tuned to component or subassembly level.

9.1.1 The Detail Design DPIEF assurance loop and risk assessment as per section 8 of this TS shall be completely executed at the end of Detail Design stage.

9.1.2 The identification and implementation of risk assessment activities associated with procedures executed during MATIC stage shall be conducted. The Define step of MATIC DPIEF assurance loop shall be completely concluded at the end of Detail Design stage and the Plan step shall start to be addressed.

9.1.3 Inspection, monitoring, testing, and maintenance activities to be undertaken as part of the ITMM plan for integrity management in Operations stage shall be considered in the scope of risk assessments conducted during Detail Design stage. The Define and Plan steps of Operations DPIEF assurance loop shall start to be addressed, as per sections 11.2 and 11.3.

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9.1.4 SUPPLIER shall present goals and requirements for each package and demonstrate how they will be achieved.

9.1.4.1 Goals and requirements of components and of sub-assemblies part of a package shall not deteriorate SEPS configuration goals and requirements stated in sections 5 and 8.4 of this TS.

9.2 SUPPLIER shall carry out a TRC assessment for each component of the package as per section 8.7 of this TS.

9.2.1 Lessons learned and best industry practices related to management of supply chain and operations shall be included in the TRC assessment.

9.2.2 Sub-supply participants may be needed, based on TRC evaluation.

9.3 FMECA shall be performed, as per section 8.8 of this TS, to identify failure modes and correspondent possible consequences, to prioritize areas of improvement and to identify the need of further analysis or testing. At least, the following aspects shall be addressed by FMECA during Detail Design stage:

9.3.1 A functional assessment to confirm all required functions expected to be performed by the element are fulfilled.

9.3.2 Hardware and design assessment to verify that system, packages, and components specific technical and technological details do not impact on system goals and requirements.

9.3.3 Interface assessment to verify that packages and system interfaces details do not impact on system goals and requirements.

9.3.4 Process assessment to identify and preliminarily address MATIC procedures and process deviations that may compromise system goals and requirements.

9.3.5 Integrity management assessment to preliminarily identify and address inspection, monitoring, testing, and maintenance activities to be part of ITMM plan.

9.3.6 Preparedness response scheme to preliminarily identify potential repair strategies following a failure and the value of investing in spare equipment items.

9.4 SUPPLIER shall perform risk analysis of the SEPS configuration, as per section 8.9 of this

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TS, and feedback Detail Design team with analysis results for review and implementation of inherently safer solutions wherever possible.

9.4.1 All hazards and risks to Operational Safety shall be clearly identified.

9.4.2 Human factors that may compromise Operational Safety shall be clearly identified.

9.4.3 SEPS Safety Envelope shall be identified and the permissible range of operation of operational variables shall be defined.

9.4.4 A control and monitoring system shall be designed to maintain the operational variables of SEPS Safety Envelope inside its limits and identify alarms when human intervention is needed.

9.4.5 A protection system shall be designed to prevent or mitigate the consequences of failure modes present in the system.

9.5 A RAM analysis of the SEPS configuration shall be performed, as per section 8.10 of this TS, to evaluate the ability of the system to remain in the operational state and to validate the definition of the maintenance or intervention support strategy.

9.5.1 The RAM analysis shall consider the complete SEPS in the scope of supply, integrating package and component details, to confirm that the overall production availability performance meets or exceeds expectations as agreed with PETROBRAS during Detailed Design.

9.5.2 The RAM analysis shall support the definition of package interfaces requirements.

9.5.3 The RAM analysis shall support the definition of installation, intervention, and maintenance requirements (vessel and sparing) needed to support stated production availability goals and requirements.

9.6 SUPPLIER shall review and verify that the risk assessment results are consistent with goals and requirements stated in 8.4 of this TS as agreed with PETROBRAS during Detailed Design.

9.6.1 If results demonstrates that the package delivers the required safety, availability and reliability, the component safety, reliability, and maintainability input data shall be validated as the component requirements.

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9.6.2 If results demonstrates that the package cannot meet the safety, availability and reliability specification, SUPPLIER shall state a plan to achieve the specifications, e.g., by stretching component reliabilities beyond that which has been historically achieved or by reconfiguring proposed package architecture.

9.6.3 A TRAR shall be schedule at the end of Detail Design stage as per section 8.11 of this TS.

9.7 SUPPLIER shall generate the SEPS RIAD at the end of Detail Design stage as per section 8.12 of this TS.

10 SEPS MATIC

10.1 At MATIC stage, SUPPLIER´s RIM process shall be tuned to procedural level but shall also address equipment, handling, and tools needed in each procedure execution.

10.1.1 DPIEF assurance loop covering Manufacture, Assemble and Testing phases of MATIC stage shall be completely executed before the beginning of system Installation phase.

10.1.2 The Plan step of DPIEF assurance loop covering Installation phase of MATIC stage shall be concluded before system Installation phase start-up.

10.1.3 The MATIC DPIEF assurance loop and risk assessment as per section 8 of this TS shall be completely executed at the end of MATIC stage.

10.1.4 ITMM plan, started at Detail Design stage, shall be concluded at the end of MATIC stage.

10.2 SUPPLIER shall develop detailed procedures for each MATIC phase considering, at least:

10.2.1 Verification that all integrity management activities can be performed as planned.

10.2.2 Confirmation that each equipment is manufactured, assembled, delivered, installed, and commissioned correctly.

10.2.3 Confirmation that all loads and environment conditions that each equipment is exposed to during each MATIC phase, including storage and transport, are within equipment acceptable limits.

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10.2.4 Human factors as sources of human errors and identification of possible effect of those errors on safety, reliability, and integrity. 10.2.5 Adequate QC/QA procedures ensure that reliability and integrity goals and requirements are not compromised by MATIC activities. 10.2.6 System interfaces are reviewed and addressed before SIT start up. 10.3 SUPPLIER shall carry out a TRC assessment for each procedure and associated equipment and tooling as per section 8.7 of this TS. 10.3.1 Lessons learned and best industry practices for each MATIC procedure and associated equipment and tooling shall be included in the TRC assessment. 10.3.2 SUPPLIER shall identify the participants in each procedure TRC assessment and representatives from equipment supplier and sub-suppliers, project, installation, and operation teams shall be included when needed. 10.3.3 SUPPLIER shall invite PETROBRAS to participate in each procedure TRC assessment. 10.4 SUPPLIER shall perform a P-FMECA / HAZID / HAZOP and IM-FMECA of each detailed procedure, identify technical risks and hazards associated with each of them and verify they do not compromise reliability and integrity. 10.4.1 Manufacture and Assembly detailed procedures shall: 10.4.1.1 Avoid the introduction of defects or assembly errors. 10.4.1.2 Prevent damage, overloading, shock loading or degradation during activities execution and including during transit and storage between locations. 10.4.2 Testing detailed procedures shall: 10.4.2.1 Include all pertinent information, e.g., calibration, settings, acceptance criteria, results etc. 10.4.2.2 Avoid damage to or degradation of the equipment being tested. 10.4.2.3 Provide evidence to demonstrate equipment function, performance, reliability, and			

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integrity. 10.4.2.4 Reveal any latent defects or incorrect assembly. 10.4.2.5 Restore equipment to the required post-test configuration after test completion. 10.4.2.6 Provide baseline data. 10.4.3 Topside Module’ SIT shall be performed with the complete set of equipment to be installed topside. SIT procedures for HV equipment shall cover, at least: 10.4.3.1 Verify all operation modes from motor start-up to commanded and emergency stop. 10.4.3.2 Verify all equipment interfaces. 10.4.3.3 Verify protection, control, and monitoring systems. 10.4.3.4 Verify all auxiliaries’ systems and interfaces part of the Electrical Room. 10.4.4 SEPS’ SIT shall be performed using the spare Topside HV VFD, an umbilical simulator to emulated by RLC cells similar resistance (R), inductance (L) and capacitance (C) of the real umbilical and the actual Subsea HV Motor. SIT procedures shall: 10.4.4.1 Verify all operation modes from motor start-up to commanded and emergency stop. 10.4.4.2 Verify protection, control, and monitoring systems. 10.4.4.3 Update IR measurements timeline and verify IR trend according to [6]. 10.4.5 SEPS’ SIT shall identify all adjustments in set up parameters of the Topside HV VFD previously delivered inside the Topside Module. 10.4.6 Installation and commissioning detailed procedures shall: 10.4.6.1 Update equipment set up parameters according to previous SIT activities. 10.4.6.2 Verify consistency between reference documents part of the detailed procedure and identify any unexpected changes to components, systems or procedures that impacts on safety, reliability and integrity performance during commissioning and			

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operations.

10.4.6.3 Prevent damage, overloading and degradation including during transport and storage.

10.4.6.4 Prevent delays to field start-up.

10.4.6.5 Update IR measurements timeline and verify IR trend according to [6].

10.4.7 Provide baseline data.

10.5 Before Installation phase start-up, SUPPLIER shall review and verify that the Manufacturing and Assembly registers and Testing results are consistent with goals and requirements stated in 8.4 of this TS.

10.5.1 SUPPLIER shall review and update the risk analysis with update Manufacture, Assembly and Testing information, as per section 8.9 of this TS.

10.5.2 SUPPLIER shall review and update the SEPS Safety Envelope.

10.5.3 SUPPLIER shall review and update the RAM analysis.

10.5.4 SUPPLIER shall review and update RIAD with all reliability and integrity data generated and collected of each package during MATIC stages ahead of handover to operations.

11 SEPS OPERATIONS

11.1 At Operations stage, SUPPLIER’s RIM process shall be tuned to procedural level and consider, at least:

11.1.1 Define and Plan steps of Operations stage DPIEF loop assurance shall be completely concluded at the end of Installation phase of MATIC stage. All operation and intervention procedures shall be available before system commissioning and handover to operations.

11.1.2 SUPPLIER shall implement an effective data management system to support information handover to operations including training of operation, maintenance, and intervention teams.

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11.1.3 Identification of any unexpected changes to components, systems, or procedures that impacts on safety, reliability, and integrity performance during commissioning. 11.1.4 Development of plans to update safety, reliability and integrity assessment and models prior to, or early, during operation stage. 11.1.5 Identification of actions to address any new risks to safety, reliability, integrity, and maintainability achievement arising from the changes. 11.1.6 Update the RIAD with all safety, reliability and integrity data generated during SEPS development project. RIAD shall be updated by the commissioning team ahead of handover to operations. 11.1.7 Any issues identified in any of the procedure reviews shall be considered in the context of the other procedures, to ensure that changes identified in one area are consistently addressed in all other related areas. 11.2 Define step of Operations DPIEF shall consider, at least: 11.2.1 Revision and update of system taxonomy and segmentation. 11.2.2 Revision and update of the TRC for each subassembly and component. 11.2.3 Revision and update of detailed risk assessment undertaken earlier. 11.2.4 Identification of key performance indicators for both the equipment and the integrity management activities. 11.2.5 Definition of integrity management and maintenance strategy and response actions to be undertaken depending on failure consequences and risk. 11.2.6 Revision and update of ITMM plan. Any activities in the ITMM plan that involve human intervention shall be backed up by HAZID/HAZOP to ensure any risks to the safety of personnel are identified and managed appropriately. 11.3 Plan step of Operations DPIEF shall consider, at least: 11.3.1 A communication plan involving other disciplines, e.g., process, topside facilities, etc., to ensure all relevant parties understands the ITMM task scope, integrity limits and objectives and that any relevant scope can be added or interfaced.			

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11.3.2

Integrated planned activities, where appropriate, with maintenance work for other related systems, e.g., topsides, to ensure that there is alignment in relation to scheduling, personnel on board, etc.

11.3.3

Definition of work pack contents for each ITMM activity, including drawings and acceptance criteria.

11.3.4

Verification that all tasks have clearly defined QC requirements, data management requirements, reporting requirements, and anomaly limits.

11.3.5

Verification that competencies are available to perform activities specified in the ITMM plan.

11.3.6

Definition of criteria for defined anomaly reporting limits.

11.4

SUPPLIER shall develop detailed operation procedures considering, at least:

11.4.1

A detailed P-FMECA / HAZID / HAZOP shall be performed to identify potential failures that could occur during each step of the procedure and alter the procedure to remove each failure possibility. Whenever possible, each procedure step shall include a positive record that action was carried out correctly.

11.4.2

For all equipment items and associated operations procedures, detailed risk assessment shall be undertaken to support identification of the required RIM activities during operations. Wherever possible, the risk assessment shall be an update of design assessment undertaken earlier by the project team.

11.4.3

Trouble-shooting procedures shall be developed to effectively identify failures, e.g., short-circuit, circuit unbalance, and indicate the ITMM procedures to be performed to restore system to an operable state.