SEPS SP-1005

Subsea Electrical Power System Design Requirements

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FOREWORD

The intent of this document is the development of a standard that will be accepted globally. Presently discussions are underway with IEC and IEEE about the possibility of their development of this document into a joint IEC/IEEE standard.

This, document, SEPS-SP -1005, has been compiled and approved by the following members of the SEPS JIP on behalf of their respective companies.

Company	Name
Chevron	Greg Clement
ExxonMobil	Stephen Lanier
Petrobras	Diego Barbosa
Shell	David Liney
Equinor	Steinar Midttveit
TotalEnergies	Edouard Thibaut

1 SCOPE

This International Standard is applicable to a.c. subsea power systems with a maximum rated voltage in the range 3.6kV ≤ Um ≤ 145kV. The intention is to define electrical design requirements when integrating subsea consumers (e.g. motors, compressors etc.), submarine power cables, power umbilicals, transformers, subsea power distribution equipment and connector assemblies with a topside or onshore electrical supply to form a subsea electrical system. The system may employ an inverter, for example an adjustable speed drive (ASD) or an inverter-based resource (IBR), or the system may be directly connected to a fixed frequency supply.

Typically, the topside supply will be from a shore-based transmission or distribution network grid, or from an offshore platform-based generator. For the purpose of this document the subsea power transmission or distribution system is defined to be downstream of the topside/onshore main circuit breaker. This circuit breaker is defined as the “Topside Point of Coupling” (TPC) as shown in Figure 3-1.

The document outlines the technical requirements necessary to design a subsea electrical power system. It also provides a recommended practice for performing integration testing of the system. The requirements for the topside/onshore power system upstream of the subsea transmission or distribution system main circuit breaker is not part of the scope. These power systems are described by other relevant international standards. However, the analysis that is conducted in this standard should form part of an overall electrical system design.

The scope of the document excludes d.c. transmission systems. It also excludes detailed mechanical interface requirements between components, installation, repair or corrosion protection requirements except where there is an electrical influence on the interface. A drawing that illustrates the scope of this document is shown in Figure 3-1.

2 NORMATIVE REFERENCES

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. There are sections in this document where either a U.S. or an international equivalent normative reference standard may be used. The choice of which standard to be used shall be agreed in advance between the manufacturer and purchaser using the data sheet (Appendix 1) to communicate the chosen standard.

ANSI C84.1	Electrical Power Systems Voltage Ratings (60Hz)
API 14F	Recommended Practice for Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1, and Division 2 Locations
API14FZ	Recommended Practice for Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Zone 0, Zone 1, and Zone 2 Locations
API 17N:	Recommended practice for subsea production system reliability, technical risk and integrity management
API RP 17Q:	Recommended practice on subsea equipment qualification
EN 50522	Earthing of power installations exceeding 1kV a.c.
IEC 60034-1:	Rotating electrical machines – Part 1: Rating and performance
IEC 60034-18-42:	Rotating electrical machines – Part 18-42: Partial discharge resistant electrical insulation systems (Type II) used in rotating electrical machines fed from voltage converters – qualification tests
IEC 60038:	IEC standard voltages
IEC 60059:	IEC standard current ratings
IEC 60071-1:	Insulation co-ordination – Part 1: Definitions, principles and rules
IEC 60909-0:	Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents
IEC 61000-2-1:	Electromagnetic compatibility (EMC) – Environment, Section 1: Description of the environment, Electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems
IEC 61000-2-4:	Electromagnetic compatibility (EMC) – Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances
IEC TR 61000-2-5:	Electromagnetic compatibility (EMC) – Part 2-5: Environment – Description and classification of electromagnetic environments
IEC 61800-2:	Adjustable speed electrical power drive systems – Part 2: General requirements – Rating specifications for adjustable speed a.c. power drive systems

IEC 61800-3:	Adjustable speed electrical power systems, EMC requirements and specific test methods
IEC 61850 all parts:	Communication networks and systems for power utility automation
IEC 61892-1	Mobile and fixed offshore units – Electrical installations – Part 1: General requirements and conditions
IEC/IEEE 61886-2:	Subsea equipment – Power transformers
IEEE 80	Guide for Safety in AC Substation Grounding
IEEE 141	Recommended Practice for Electric Power Distribution for Industrial Plants
IEEE 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
IEEE 399	IEEE Recommended Practice for Industrial and Commercial Power System Analysis
IEC/IEEE 61886-1:	Subsea equipment - Power connectors, penetrators and jumper assemblies with rated voltage from 3 kV (Umax = 3,6 kV) to 30 kV (Umax = 36 kV)
IEEE 519:	Recommended practice and requirements for harmonic control in electrical power systems
IEEE 1313.2	Guide for the Application of Insulation Coordination
IEEE 1566	IEEE Standard for Performance of Adjustable Speed AC Drives Rated 375 kW and Larger
IEEE 3002.2	IEEE Recommended Practice for Conducting Load-Flow Studies and Analysis of Industrial and Commercial Power Systems
IEEE 3002.3	IEEE Recommended Practice for Conducting Short-Circuit Studies and Analysis of Industrial and Commercial Power Systems
SEPS SP1003:	Subsea electrical motors
ISO 9001:	Quality management systems

3 TERMS, DEFINITIONS AND ABBREVIATED TERMS

For the purposes of this document, the following terms apply.

3.1 Terms and definitions

3.1.1 Cathodic Protection

Reduction or prevention of corrosion by making a metal the cathode in a conducting medium by means of a direct current (impressed or galvanic).

3.1.2 Connector Assembly

Any assembly of wet and/or dry mate connectors, penetrators, cable terminations, cable pigtails or jumper cables between subsea components – or any combination of these.

3.1.3 Connector

Fully insulated termination permitting the connection and the disconnection of an electrical cable to other equipment.

3.1.4 Corrosion protection

A means of preventing or reducing the rate of metallic corrosion by any means such as coatings, paints and cathodic protection.

3.1.5 Integration Test

A test in which each individual component is integrated into a system and operated in such a way as to test that the system and its components perform as expected.

3.1.6 Rapid Gas Decompression

An extreme depressurization event from high pressure (hundreds of bar) to low pressure (tens of bars down to atmospheric) in order of seconds, that can occur in a production system with gas present. The phenomenon is also known as explosive decompression.

3.1.7 Rated Absolute Pressure

The maximum absolute pressure that subsea equipment has been designed to operate at under the specified conditions of use. For equipment that is designed to operate under pressure balanced conditions, only one value of rated absolute pressure shall be specified. For equipment that is designed to operate with different pressures on either side of the equipment housing, two values of rated absolute pressure shall be specified. RAP-1 shall be used to refer to the maximum rated absolute pressure on the external or outboard side of the housing and RAP-2 shall be used to refer to the maximum rated absolute pressure on the internal or inboard side of the housing.

Note 1: The rated absolute pressure value shall be used to describe the pressure rating of the equipment and it should not be confused with the maximum design or test pressure to which the equipment must be subjected in order to qualify it for service.

3.1.8 **Rated Insulation Level**

The maximum voltage that the electrical insulation of the system can withstand without a reduction in the design life of the system in order to provide the required margin of safety when the system is operating at the rated voltage (normal working voltage).

Note 1: For clarity Rated Insulation Level is not the same as the voltage withstand level which is a short-term over-voltage to test the electrical strength of the electrical insulation nor is it the same as the system rated voltage.

3.1.9 **Rated Voltage**

The nominal line voltage (phase to phase voltage Un according to IEC 60038) at which the system is designed to operate continuously under specified operating conditions. This is the voltage that shall be displayed on the rating plates of the subsea equipment and the voltage at which the performance characteristics of the system shall be established.

Note: Rated voltage is not the maximum voltage that the system can withstand as margins of safety require the system to tolerate an over-voltage as defined in the data sheet (Appendix 1).

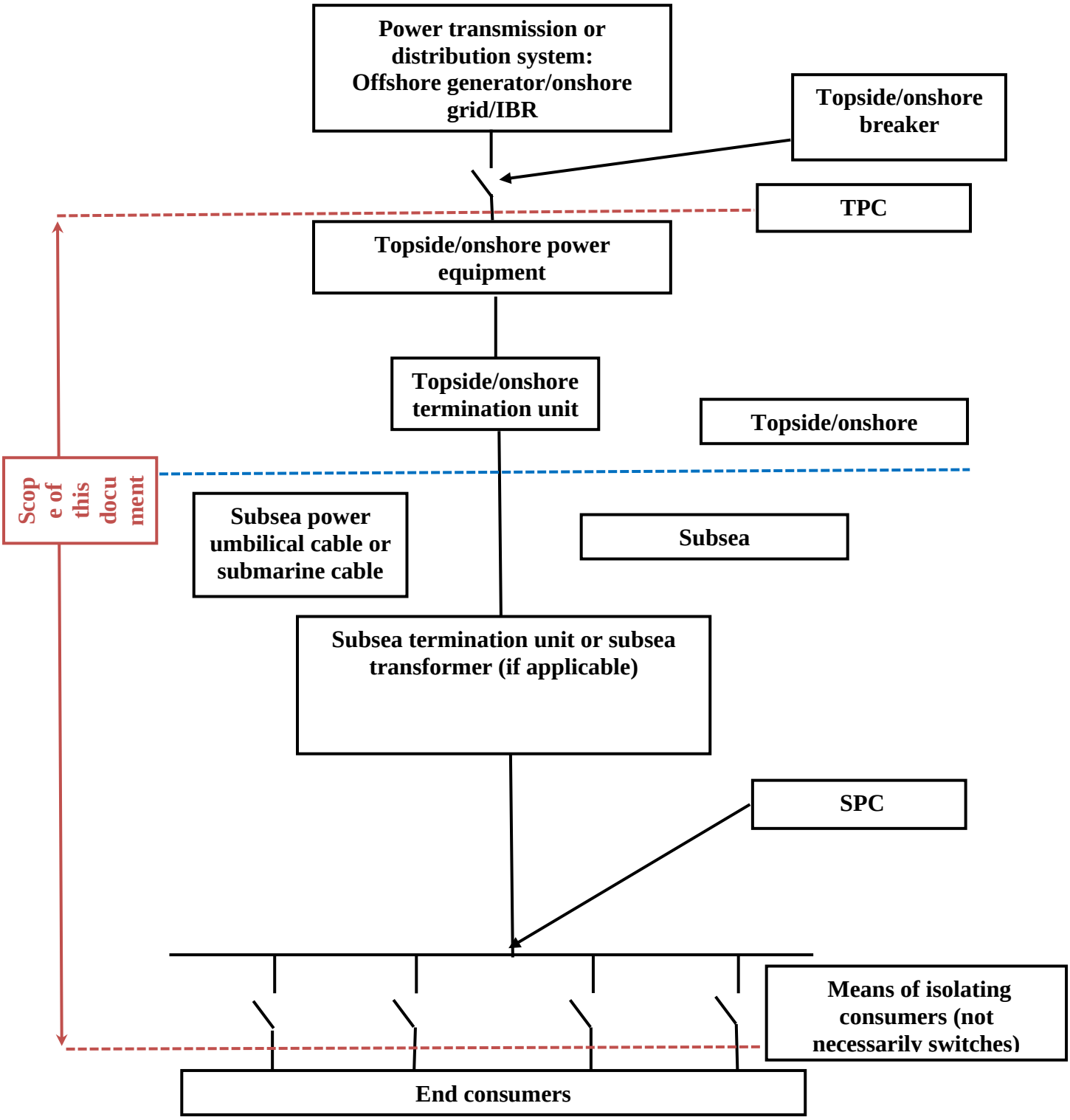
3.1.10 **Subsea Point of Coupling**

The point on a subsea network that is electrically closest to a subsea consumer and at which point other consumers can be connected. Refer to Figure 3-1.

3.1.11 **Topside Point of Coupling**

The connection point between the subsea network and the output side of the topside breaker. Refer to Figure 3-1.

Figure 3-1 An example of a subsea electrical system to illustrate the scope of the document and define the Points of Coupling



3.2 Abbreviated terms

3.2.1 **AIS**

Automatic Identification System

3.2.2 **ANSI**

American National Standards Institute

3.2.3 **API**

American Petroleum Institute

3.2.4 **ASD**

Adjustable Speed Drive. Also known as VFD (Variable Frequency Drive) and VSD (Variable Speed Drive). For consistency the term ASD is used throughout this document according to the definition given in SEPS SP 1003

3.2.5 **AUV**

Autonomous Underwater Vehicle

3.2.6 **CT**

Current Transducer

3.2.7 **CP**

Cathodic Protection

3.2.8 **DAS**

Distributed Acoustic Sensing

3.2.9 **DSS**

Distributed Strain Sensing

3.2.10 **DTS**

Distributed Temperature Sensing

3.2.11 **EMC**

Electromagnetic Compatibility

3.2.12 **EMI**

Electromagnetic Interference

3.2.13 **FEA**

Finite Element Analysis

3.2.14 **FMECA**

Failure Mode Effect and Criticality Analysis

3.2.15 **HAZOP**

Hazard and Operability Study

3.2.16 **HV**

High Voltage

3.2.17 **IBR**

Inverter Based Resource

3.2.18 **IEC**

International Electrical Committee

3.2.19 **IEEE**

Institute of Electrical and Electronics Engineers

3.2.20 **IR**

Insulation Resistance

3.2.21 **ISO**

International Organization for Standardization

3.2.22 **IT**

īnsulātum terra – ungrounded, isolated earth

3.2.23 **IVIC**

Impulse Voltage Insulation Class

3.2.24 **JIP**

Joint Industry Project

3.2.25 **LCM**

Earth Leakage Current Monitoring

3.2.26 **LI**

Lightning Impulse

3.2.27 **LIMS**

Line Insulation Resistance Monitoring

3.2.28 **LiRA**

Line Resonance Analysis

3.2.29 **LV**

Low Voltage

3.2.30 **MER**

Main Earth Reference

3.2.31 **NEMA**

National Electrical Manufacturers Association

3.2.32 **OTDR**

Optical Time Domain Reflectometry

3.2.33 **PT**

Pressure Transducer

3.2.34 **RAP**

Rated Absolute Pressure

3.2.35 **ROV**

Remotely Operated Vehicle

3.2.36 **SEPS**

Subsea Electrical Power Standardisation

3.2.37 **SPC**

Subsea Point of Coupling

3.2.38 **TDR**

Time Domain Reflectometry

3.2.39 **TRL**

Technology Readiness Level

3.2.40 **THD**

Total Harmonic Distortion

3.2.41 **TPC**

Topside Point of Coupling

3.2.42 **TT**

Temperature Transducer

3.2.43 **Um**

Highest voltage for equipment

3.2.44 **Un**

Nominal rated voltage of the system

3.2.45 **VT**

Voltage Transducer

4 SUBSEA ELECTRICAL SYSTEM DESIGN REQUIREMENTS

4.1 General Requirements

Reference shall be made to API 14F and API 14FZ. Consideration shall be given to the following system requirements:

- 4.1.a Operating conditions
- 4.1.b Environmental conditions
- 4.1.c Equipment ratings and specified tolerances on each rating
- 4.1.d Design margins of safety (noting that margins of safety may also have been applied at the equipment level)
- 4.1.e Fault types and fault tolerance
- 4.1.f System protection
- 4.1.g System redundancy
- 4.1.h Control systems (for subsea power system)
- 4.1.i Electronic communication protocols
- 4.1.j System Earthing / Grounding
- 4.1.k Earth bonding of subsea equipment components
- 4.1.l Stray and circulating currents including from the CP system
- 4.1.m EMC
- 4.1.n Harmonic distortion
- 4.1.o System shut down and restarting
- 4.1.p Availability and reliability requirements
- 4.1.q System control and condition monitoring
- 4.1.r The management of interfaces and interactions between different manufacturer's equipment

The subsea system shall be designed with a focus on safety, availability and reliability:

- 4.1.1 No single failure shall lead to parts of the system being unprotected or exceeding their design limits with respect to current or insulation level
- 4.1.2 There shall be a means of isolating the power supply prior to conducting intervention operations (for example making and breaking subsea connections)
- 4.1.3 Topside/onshore electrical protection of the subsea system shall be provided. For systems employing an ASD or IBR supply, the ASD or IBR shall have an integrated electrical protection system to protect all downstream electrical equipment to which it is connected
- 4.1.4 Means shall be provided to detect abnormal operating conditions and isolate a faulty part of the power system so that the healthy part of the power system operates normally after a fault interruption
- 4.1.5 There shall be a means at the topside or onshore supply of earthing the entire subsea system during maintenance and repair work. For systems with a Um of greater than 15kV there shall be the provision of permanently installed earthing switches that are rated to the required fault level

4.1.6 It should be possible to disconnect and isolate the subsea power system from the topside/onshore power supply to allow for measurements during commissioning and fault finding

4.1.7 The electrical insulation of the subsea network shall be designed to withstand the highest (peak-peak) repetitive voltage level and the required fault levels. A rated insulation level shall be specified to all equipment manufacturers using the data sheet (Appendix 1)

4.1.8 For high resistance and isolated system earthing, the data sheet (Appendix 1) shall be used to define whether the system shall be designed to operate continuously with a line to earth short circuit or not. If energization for a short duration with a line to earth short circuit is expected, then this shall be specified in the data sheet

4.1.9 The modelling of the subsea system should form part of the overall electrical system design analysis to ensure an integrated approach is taken to the design of the electrical system

4.1.10 Consideration should be given to achieving the facility design life objectives including identifying equipment and components not designed to be retrieved as well as equipment operating duration targets between maintenance retrieval. Equipment requiring maintenance or replacement shall be designed to be dis-connectable and surface retrievable.

4.1.11 Obsolescence should be considered when selecting and designing a reliable electrical system. Obsolescence is a particular issue for electrical systems with most electronics becoming obsolete within 20 years

4.1.12 Consideration shall be given to the thermal rating of the system in respect of equipment operating in different environmental conditions and at different temperatures

Note 1 to entry: An example of the last point is an umbilical cable where it will mostly be cooled by seawater except where it is suspended in air between a platform and the ocean. In such cases it is possible for the thermal limitations at this point to determine the rating of the entire system if not taken into account.

4.2 System Electrical Performance Requirements

4.2.1 For subsea networks that are supplying a motor load, reference shall be made to SEPS SP-1003 and the torque speed envelop contained therein. In such instances the electrical power supply shall be capable of generating a torque during motor start which is 30 % higher than the maximum break-away torque specified for the motor. Lower values can be specified in the data sheet (Appendix 1) if the breakaway torque is documented by calculations and testing for a similar motor design

4.2.2 Unless otherwise specified in the data sheet (Appendix 1), the system shall be designed to operate with voltage harmonics according to Table 4-2

4.2.3 For systems utilizing a subsea transformer, reference shall be made to IEC/IEEE 61886-2

4.2.4 "Unless otherwise specified in the data sheet (Appendix 1), the subsea power system shall be designed so that all subsea electrical equipment have a minimum 10 % higher

current rating than the rated current of the end consumer(s) under normal operating conditions. Reference shall be made to the thermal analysis required in Section 5

Note 1 to entry. The maximum current rating of cables and connectors may be dictated by conditions other than the capacity of the load, such as by voltage drop on long step-outs or by environmental conditions. This is a particularly important consideration when performing topside tests when the cooling effect of seawater will be absent unless a shallow water test is performed.

4.2.5 The nominal rated voltage Un of the system should be as specified in Table 4-1a, 4.1b or 4.1c.

4.2.6 The rated current of the system should be as specified in IEC 60059

4.2.7 The insulation should be evaluated to ensure that the required design life (as specified in the data sheet, Appendix 1) can be achieved when operating with a line to earth short circuit

4.2.8 For three-phase systems designed to operate with an earth fault, the maximum voltage rating Um for the equipment in the system according to IEC 60038 shall be at least one voltage class higher than the nominal rating Un of the system. This also applies to the rated insulation level of the entire system. The insulation should be evaluated to ensure that the required design life (as specified in the data sheet, Appendix 1) can be achieved when operating with an earth fault.

4.2.9 Unless otherwise specified in the data sheet (Appendix 1), the subsea transmission system shall be designed and dimensioned so that the voltage drop across the subsea cable shall not exceed 15% under steady state conditions at nominal electrical loading (rated voltage, rated frequency and load)

4.2.10 The maximum rate of rise of voltage du/dt at the subsea point of coupling shall be no greater than 3kV/µs

4.2.11 The impulse voltage stress and repetition rate at the point of subsea coupling shall be within the systems Impulse Voltage Insulation Class (IEC 60034-18-42)

4.2.12 The repetitive peak-peak voltage stress should be evaluated for the whole system for worst case conditions to ensure that the insulation class is sufficient for the enhancement of the peak-peak voltage when supplied by an ASD or IBR.

4.2.13 For systems supplied directly from a main grid or generator, the maximum nominal system voltages shall be according to Table 4-1a, 4-1b or 4-2c as defined in the datasheet (Appendix 1). Under no circumstances shall the nominal voltage of the system Un exceed the maximum voltage rating of the equipment Um

Table 4-1a Nominal system voltages for systems supplied directly from a grid or generator according to IEC 60038 Series I

Highest Voltage for Equipment Um (kV)										
IEC 60038 Series I 50Hz & 60Hz	3.6	7.2	12.0	17.5	24.0	36.0	52.0	72.5	123.0	145.0
Maximum Nominal System Voltage Un (kV)										
	3	6	10	15	20	30	45	66	110	132

Table 4-1b Nominal system voltages for systems supplied directly from a grid or generator according to IEC 60038 Series II

Highest Voltage for Equipment Um (kV)										
IEC 60038 Series II 60Hz	4.4	13.2	13.97	14.52	26.4	36.5				
Maximum Nominal System Voltage Un (kV)										
	4.16	12.47	13.2	13.8	24.94	34.5				

Table 4-1c Nominal system voltages for systems supplied directly from a grid or generator according to ANSI C84.1 (NEMA practice)

Highest Voltage for Equipment Um (kV)											
ANSI C84.1	6.9	13.8	27.0	38.0	46.0	72.5	145.0				
Maximum Nominal System Voltage Un (kV)											
	6.6	13.2	25.0	34.5	44.0	69.0	115.0				

4.3 System and equipment requirements at the Subsea Point of Coupling

Unless otherwise specified in the data sheet (Appendix 1), the system requirements and equipment immunity levels shall be according to Table 4-2. Variations are expressed in terms of deviation from the nominal service requirements.

Table 4-2 Requirements at the Subsea Point of Coupling

Parameter	System design requirement	Equipment immunity level	Comments
Voltage tolerance (continuous)	±10%	+10% -15%	For systems containing an ASD or IBR, the ASD/IBR shall be capable of delivering full power with input voltage variations of up to ±5%
Slow voltage transient variations	+25% -20%	+30% -25%	For example, as a result of changing electrical load conditions
Maximum voltage variation	±25%	±30%	Voltage excursions (i.e. the sum of transient and steady state variations)
Voltage transient recovery time	≤1.5s	1.5s	If this requirement cannot be met due, for example, the use of a transformer tap changer, the requirement shall be agreed in the data sheet (Appendix 1).
Voltage unbalance tolerance (U-/U+) note 1	Class 1	Class 2	Including phase voltage unbalance as a result of an unbalanced load (ref. IEC61000-2-4)
Supply frequency variations	±5%	±5%	Excludes systems downstream of an ASD/IBR.
Supply frequency transient variations	±10%	±15%	Averaged over time
Maximum supply frequency transient	±12.5%	±15%	Maximum frequency excursion (sum of transient and steady state variations)
Supply frequency transient recovery time	≤5s	5s	
Voltage harmonic class (unless specified otherwise)	Class 2 (8%)	Class 2 (8%)	Ref. IEC61000-2-4. If inter-harmonic components are present, theses shall be considered at the system design stage
DC component	Data sheet item	Data sheet item	Ref. IEC61000-2-4
Induced voltages	Data sheet item	Data sheet item	Ref. IEC61000-2-5
Short interruptions	Refer to Note 2	Refer to Note 2	Ref. IEC61000-2-5

Note 1: Where 3-phase a.c. motors are connected, the system negative-sequence component shall not exceed 1% of the positive sequence component averaged over a long period of time (at least the thermal time constant of the machine). The zero-sequence component shall not exceed 1% of the positive-sequence component.

Note 2: ASD, IBR subsea auxiliary systems and switchgear subsea control systems shall remain energized during a short interruption with a voltage level of 0 % for a duration of ≤500ms (i.e. system functionality and control shall be maintained during this period). This shall be documented and tested according to IEC 61000-4-11, IEC 61000-4-34 or IEC 61000-4-29.

4.4 Electrical requirements at terminals of subsea motors supplied by ASD or IBR.

Where the consumer is a subsea motor that is supplied by an ASD or IBR, the peak voltage stress levels at the motor terminals shall not exceed the capabilities of the machine electrical insulation. Unless otherwise specified in the data sheet (Appendix 1), the requirements listed in Table 4-3 shall apply to topside and subsea ASDs/IBRs. For North American practice reference should be made to IEEE 1566.

Table 4-3 ASD & IBR system requirements at the motor terminals.

Characteristic	System requirement	Comments
Voltage tolerance (continuous)	Zone A	Ref. IEC 60034-1 Figure 12 for the rated frequency given in the datasheet
Frequency tolerance (continuous)	Zone A	Ref. IEC 60034-1 Figure 12 for the rated frequency given in the datasheet
Voltage/frequency ratio tolerance (U/f continuous)	±5%	
Voltage/frequency ratio tolerance (U/f transient)	±10%	
Voltage neg. sequence/pos. sequence (continuous)	≤1%	
Voltage zero sequence/pos. sequence (continuous)	≤1%	
Dynamic voltage rise	≤ 3kV/µs	Ref IEC 61800-4

4.5 Electrical system grounding and earthing requirements

The subsea earthing strategy shall be clearly recorded and communicated to all parties. This is to ensure that the various manufacturers and installation contractors provide equipment and services that are consistent with this strategy. The provision of system protection shall also be consistent with the subsea earthing strategy.

As a minimum the subsea earthing strategy shall consider:

4.5.1 A description and definition of how to establish a subsea main earth reference (MER)
4.5.2 A description of which equipment is to be connected to the MER and how this connection will be made
4.5.3 The specified requirements for service and fault conditions that are given in the data sheet (Appendix 1)
4.5.4 Selection of earth conductor sizes, earth boss dimensions, bolt sizes etc. consistent with the required service and fault conditions at the various points in the system
4.5.5 Handling and connection of cable screens and connectors including a description of dimensioning, connection, isolation, required insulation level if isolating
4.5.6 Consideration of the impact of the subsea earthing strategy on corrosion protection including the effects of stray currents and fixed or floating potential differences
4.5.7 Determination of system discharge paths and discharge duration to permit the safe operation of system earthing switches as a function of the discharge duration
4.5.8 The condition monitoring requirements shall be consistent with the earthing strategy
4.5.9 An assessment of the impact of earth circulating currents and if necessary, a thermal de-rating of the system to accommodate them
4.5.10 Selection of earth conductor sizes, earth boss dimensions, bolt sizes, bonding jumpers, equipment grounding conductors so they are consistent with the required service and fault conditions at the various points in the system
4.5.11 Requirements for checking, verifying and testing of earthing system after installation
4.5.12 Description of requirements the protective and functional earthing system
4.5.13 Onshore and topsides bonding, earthing and equipment grounding requirements are outside the scope of this document and should be follow the requirements of the local authority having jurisdiction.

A recommended practice for system earthing is given in Table 4-4. An earthing study shall be conducted to evaluate the various earthing concepts considering at a minimum: escalating voltages during a ground fault, charging currents, protection philosophy, etc. In the event multiple methods are acceptable, the end user shall determine the final methodology utilized.

Table 4-4 Recommended system earthing methods.

Operating voltage Un (kV)	Single phase earth fault current (A)	Recommended system earthing method	Application
>20	Not applicable	Solid earthing/ resistance earthing	All systems
≤20	>5	Solid earthing/ resistance earthing	Topside offshore transformers Transformers located onshore shall be subject to project specific requirements
	≤5	Isolated/high resistance earthing	
	>20	Solid earthing/ resistance earthing	Subsea transformers only
	≤20	Solid earthing/ resistance earthing	Subsea transformers only
	≤20	Isolated/high resistance earthing	Subsea transformers only

For an isolated/high resistance earthing the IMS shall be installed to monitor insulation health. A remote alarm signal should be provided when the insulation level is below acceptable level. Arcing ground faults shall be considered when selecting isolated system earthing and the expected overvoltage should be calculated.

For isolated/high resistance earthing grounding system, current transformers shall be provided in the neutral. Depending on the operational requirements with an earth fault, a remote alarm or trip signal shall be provided. The resistor value shall be selected according to IEC 61892-2. EN 50522, IEC 61892 and IEEE 80 may be used as a guidance for the earthing system design.

4.6 Documentation

The basis for communicating system data between the system designer and the user is the data sheet (Appendix 1). These requirements shall be communicated and agreed by all parties involved in the design and operation of equipment in the system.

For the subsea system design analysis (Section 5), reports shall be produced to document and communicate the design strategy for the various aspects of the system. Reference may be made to API RP 17Q for a standardized process for documentation. In addition to communicating the results of studies and analysis, the reports shall outline the system architecture including ancillary devices such as earth switches, interlocking safety devices and condition monitoring systems.
The system designer shall provide a written manual detailing operation and maintenance of the system including its ancillary and auxiliary systems. This shall include a procedure for system isolation and fault finding. Safety considerations at all stages of testing, installation,

energization, operation, shutdown, maintenance and recovery shall be documented and communicated to all relevant parties.

5 SUBSEA SYSTEM DESIGN ANALYSIS

5.1 General requirements

It is recommended that the following should be undertaken and documented in order to verify the design of the subsea electrical system and its component parts:

5.1.1 System protection analysis
5.1.2 System earthing analysis
5.1.3 Load flow calculations
5.1.4 Short circuit analysis
5.1.5 Power system dynamic/transient analysis
5.1.6 Harmonic analysis
5.1.7 Electrical insulation co-ordination
5.1.8 Subsea power system design strategy including system availability
5.1.9 Transmission and distribution system analysis
5.1.10 EMC analysis
5.1.11 Thermal analysis
5.1.12 Reliability analysis
5.1.13 Risk analysis and resulting safety manual

Whilst conducting theses analyses, consideration shall be given for the presence of stored energy in the system and the implications for human safety and equipment integrity. For example, in the case of PM motors, the possibility of process flow causing the machine to act as a generator and develop dangerous voltages at the topside terminals during maintenance despite the terminals being isolated from the electrical supply. Consideration shall also be given in the system design for the requirements of testing at both the pre-commissioning stage (topside) and commissioning stage (subsea) and the need for any ancillary systems to facilitate these activities (e.g. test connections, control system test circuits, by pass circuits, test sensors and data monitoring etc.). It is also recommended that consideration shall be given to the requirements for production recycle loops and their cooling in order to test the system when it is subsea prior to production.

The design analysis documentation shall outline the design and operation strategy of the complete power transmission and distribution system and shall act as guidance for the detail design of the system and its component parts, both hardware and software. It shall also include an overview of the power system, system earthing for each section of the system (Section 4.5), interlocking and protection principles, control system architecture, operational requirements and interfaces between the control system and power equipment.

5.2 System Protection Analysis

A power system protection strategy shall be prepared with reference to the relevant parts of IEC 61850 or IEEE 242 and IEEE 399. This document shall form the basis for the selection of protective devices. It shall also outline the process for the safe disconnection and isolation of parts of the system for maintenance and fault investigation. This study shall take into account the output from the insulation co-ordination study in Section 5.8. The protection strategy shall include as a minimum:

5.2.1 Protection zones in the power system
5.2.2 Methods of protection discrimination
5.2.3 Types of relays and their protective functions
5.2.4 Method and speed of communication for the system protection system
5.2.5 The location of voltage and current transformers or transducers
5.2.6 The location of other monitoring systems such as voltage, current and temperature sensors
5.2.7 The provision of Insulation Monitoring Systems
5.2.8 Effect of stored energy in the system on the performance of protective devices during fault conditions

5.3 System Earthing Analysis

The requirements for system earthing are detailed in Section 4.5. The earthing system shall be analyzed to determine the electrical characteristics of the system, including fault discharge times and a calculation of transient potential differences in the earthing system. Where there is a requirement to insulate earth circuits from other circuits that are at earth potential, the required insulation level shall be calculated and specified to all parties involved.

Note 1. An example is metallic hydraulic lines that are insulated within an umbilical that contains high power conductors in order to prevent induced circulating currents that could promote corrosion.

5.4 Load flow calculations

Load flow calculations shall be performed to verify the voltage profile and circuit loading under steady state conditions. These calculations shall include:

5.4.1 Different network configurations if applicable (e.g. open bus tie breaker, closed bus tie breaker with single incoming supply etc.)

5.4.2 Different load scenarios (maximum, minimum and no load, for motors maximum and minimum speeds etc.)

5.4.3 For systems that may operate unbalanced, unbalanced load flow analysis shall be performed to verify that unbalanced voltages are within the system design tolerances as required by Sections 4.3 and 4.4

5.4.4 Busbar voltage and phase analysis

5.4.5 Maximum and minimum short circuit currents with reference to Section 5.2

5.4.6 Voltages and voltage drops in the transmission system under different load conditions (including, for example, the Ferranti effect under no load, open circuit conditions)

5.4.7 Voltage regulation at the supply under different load conditions

5.4.8 Calculation of system voltages during connection and disconnection for all loading scenarios

5.4.9 Active and reactive power flow in the system including filters, reactors, load compensators, cables and consumers. Calculation of percentage loading as a function of total power available

5.4.10 Calculation of power factor and requirement for power factor compensation

5.4.11 Analysis for recommended settings of transformer tappings if present

For North American practice reference should be made to IEEE 3002.2

5.5 Short circuit analysis

Short circuit calculations shall be performed to determine the maximum mechanical and thermal stresses during fault conditions. The results shall be used to specify equipment ratings for the system and to determine the settings for protective devices. Short circuit calculations may be performed under steady state conditions with consideration to the presence of rotating equipment in order to identify the least favourable conditions and these shall form the basis for specifying equipment. For the maximum and minimum power conditions and for all bus sections, the following shall be derived as applicable:

5.5.1 Three-phase short circuit current with all lines energised

5.5.2 Line-line short circuit current with both lines energised

5.5.3 Line-line short circuit with one line earthed

5.5.4 Line-earth short circuit current

5.5.5 Thermal equivalent short circuit current may be calculated using the method described in IEC 60909-0

5.5.6 Earth fault currents for un-grounded systems

For North American Practice reference should be made to IEEE 3002.3

Note 1: For asymmetrical short circuits applied to the secondary of a delta-wye transformer, consideration should be given for the protection settings due to currents that may circulate in the primary of the transformer in the phases that are not involved in the short circuit.

5.6 Power system dynamic analysis

For North American practice reference should be made to IEEE 3002.2

The dynamic analysis of the power system shall include as a minimum:

5.6.1 The boost factor and the required rating for transformers

5.6.2 A calculation to verify that the required starting torque can be delivered to motor loads

5.6.3 Derivation of motor start up curves

5.6.4 Analysis of load changes

5.6.5 Load rejection at maximum and minimum load conditions

5.6.6 Zero-miss effects on the system during energisation

5.6.7 Derivation of in-rush currents

5.6.8 Assess the requirement for point on wave closing

5.6.9 Voltage and frequency stability analysis

5.6.10 Effect of crow bar activation

5.7 Harmonic analysis

A study shall be undertaken to verify that harmonic and inter-harmonic distortion within the system under all operating modes (including all combinations of loading) is within acceptable levels. Reference may be made to IEEE519 or IEC61000-2-4. As a minimum the following shall be documented:

5.7.1 Harmonic distortion spectrum for each disturbance source IEC61000-2-4

5.7.2 Plot of the system impedance as a function of distortion frequency and this shall include the impedance as determined from both the TPC and the SPC

5.7.3 Calculation of harmonic current amplification at parallel resonant frequencies

5.7.4 Calculation of harmonic voltage amplification at parallel resonant frequencies

5.7.5 Specification of equipment ratings to accommodate voltage and current amplification

5.7.6 Calculation of harmonic current in supply feeders

5.7.7 Calculation of THD voltage and current as a % of fundamental

5.7.8 Calculation of single voltage harmonics (inter-harmonics shall be considered)

5.7.9 Specification of harmonic distortion and resonance reduction methods where applicable (e.g. filters, series inductors, surge arrestors etc.)

5.8 Electromagnetic interference and thermal analysis

Electromagnetic interference (EMI) and thermal FEA analysis for the power umbilical / HV submarine cable system shall be performed for each cross-section design. The analysis shall be performed at rated current, fundamental frequency with the effect of harmonics, adjacent structures / assets, soil thermal resistivity and environmental conditions such as ambient temperature and solar exposure where relevant and in accordance with the requirement stated in the datasheet. Modelling shall address the possibility of cross-talk and interference in multifunctional umbilicals where power and communication lines are in close proximity. EMI studies shall include effects of eddy current and skin effect. Reference shall be made to IEC 61000-2-1, IEC 61000-2-4 and IEC 61800-3.

The analysis report as a minimum shall include design basis, study results and an executive summary. FEA results shall provide thermal and EMI results at the conductor screen, optical fibers and other components and include induced current, induced voltage and temperature profile in every component within each power umbilical / HV submarine cable based on the study cases described in the scope of study. Depending upon the project requirements, the following case studies should be considered in the thermal analysis:

5.8.1 Topside dynamic riser pigtails above hang-off
5.8.2 Topsides cable on-board the offshore vessel
5.8.3 Dynamic riser in I-tube in air and in seawater
5.8.4 Dynamic riser in bend stiffener in air or in seawater depending on project requirement
5.8.5 Static power umbilical / HV submarine cable partially buried in seabed
5.8.6 Static power umbilical / HV submarine at asset crossing
5.8.7 Power umbilical / HV submarine cable in HDD including junction pit where it splices to a land power cable
5.8.8 Field splices

5.9 Electrical insulation co-ordination

To ensure that the electrical insulation is optimized for the required service and fault conditions, the following information shall be considered when specifying the insulation classes and operating voltages:

5.9.1 Voltage harmonics and resonance and mitigations to reduce them
5.9.2 Operation with an earth fault in systems with an ungrounded neutral point when specified in the data sheet (Appendix 1)
5.9.3 Over voltages as defined by IEC 60071-1 section 5.2
5.9.4 Switching transients
5.9.5 Transient recovery voltage evaluation
5.9.6 Induced voltages. Special consideration shall be given to multifunction umbilicals with controls and power functions
5.9.7 Load rejection effect on both the supply and the transmission system

5.9.8 Determination of peak repetitive transient voltages at the SPC for ASD or IBR supplied systems and verification that they are within the impulse voltage insulation class (IVIC) of the equipment in the system according to IEC 60034-18-42

5.9.9 In the case of supply from an ASD or IBR, a calculation of the repetitive peak-peak voltage stress in the system for worst case conditions and an evaluation against the insulation class to verify that the insulation class is sufficient to withstand the maximum peak-peak voltages.

5.9.10 For North American practice reference shall be made to IEEE 1313.2

5.10 Technology Readiness Assessment

It is recommended that the following studies should be undertaken:

5.10.1 A technology readiness assessment according to API 17N and API 17Q in order to ensure that the required TRL is achieved

5.10.2 A reliability analysis at the equipment level including FMECAs

5.10.3 A HAZOP analysis in accordance with the end user requirements with reference to IEEE Standards 80 and 141.

In each case, particular consideration should be given to interfaces and coupling of equipment where interactions may occur that have not been previously expected or evaluated. This may form part of the input into the system integration testing in Section 7 in order to evaluate and test any unknowns that have arisen during the analysis.

A risk classification assessment (TRC ref: API 17N), shall also be undertaken to determine the level of risk associated with delivering a qualified component or system. This will provide insight as to what level of further testing is required to address any issues raised during the concept evaluation, FEED study, FMECA and HAZOP analyses.

Where significant technology gaps have been identified, it is recommended that integration testing of the system should be performed (Section 7). Project responsibility is to define to what extent this testing has to be representative of the 'use case' to mitigate the identified risk level from TRC evaluation.

6 INSTRUMENTATION CONDITION MONITORING, MAINTENANCE AND DIAGNOSTIC TESTING

6.1 Recommendations

It is recommended that consideration be given early in the project to the requirements for system health condition monitoring, maintenance and diagnostic testing so that these requirements can be integrated into the system design. Consideration should be given as to whether these can be built into the system for online condition monitoring as opposed to monitoring that requires intervention. The following parameters and measurement techniques are recommended for consideration.

6.1.1 Line Insulation Resistance Monitoring (LIMS); online, limited for use on IT (īnsulātum terra – ungrounded, isolated earth) systems

6.1.2 Earth Leakage current monitoring (LCM); online

6.1.3 High Resistance Fault Locating; offline, requires access to the conductors and a healthy conductor for comparison, techniques such as Murray loop, Varely loop or Hilborn loop can be used to detect high resistance faults or short circuits within cables

6.1.4 Voltage Transducer (VT) and Current Transducer (CT); online; application subsea is similar to regular onshore CTs and VTs

6.1.5 Line Resonance Analysis (LiRA); typically recommended for use offline for higher voltage systems, although there are some online applications; used to detect local or global changes in a cable's R, L, C and G parameters

6.1.6 Pressure Transducer (PT) and Temperature Transducer (TT); online, used for condition monitoring of motors and transformers etc.

6.1.7 Time Domain Reflectometry (TDR); offline, used to detect/locate significant changes in a cable's transmission characteristics such as a short circuit, open circuit or change of geometry

6.1.8 Optical Time Domain Reflectometry (OTDR); online/offline, similar technique to TDR but utilizing optical fibres as the transmission system; may be used to detect/locate damage to a cable although consideration should be given to the possibility of fibre damage by short circuit within the power cores or by 3rd party operations

6.1.9 Bragg grating sensors; online, utilizes imprinted optical gratings on fibre optic cable to infer many different measurands as a result of strain imparted onto the fibre; sensors do not require power and can measure strain, voltage, current, pressure, temperature, vibration etc.

6.1.10 Distributed Temperature Sensing (DTS); online, utilizes optical fibres as a distributed temperature sensor; used to monitor temperatures along cables, accuracy dependent on the duration of the scan time, cable length and the proximity of the fibre to the power conductor

6.1.11 Distributed Acoustic Sensing (DAS); online, utilizes optical fibres as distributed microphones that can be used from quasi DC to ~10kHz; uses involve intrusion detection, strain monitoring and fault location etc.

6.1.12 Distributed Strain Sensing (DSS);online, can utilize optical fibres or fibres with thousands of weakly imprinted optical gratings; technology under development for

power cables; key consideration is how to couple the strain imparted onto the power cable into the fibre

6.1.13 Acoustic and electromagnetic sensing; online; discrete sensors utilizing hydrophones and electromagnetic sensors

6.1.14 Autonomous Underwater Vehicle (AUV) or Remotely Operated Vehicle (ROV); used for cable route inspection or subsea equipment inspection/maintenance

6.1.15 Automatic Identification System (AIS); uses transponders on marine vessels to track their position; can be used as early warning for vessels crossing underwater assets

7 SYSTEM INTEGRATION AND TEST REQUIREMENTS

7.1 General

Following the TRL analysis in Section 5.10, an assessment shall be made as to what new technologies require further evaluation in order to verify that the required TRL (API 17N) can be achieved. An assessment shall also be made to determine if further testing is required in order to evaluate any issues raised during the concept evaluation, feed study, FMECA (API 17Q) and HAZOP analyses. Where significant technology gaps have been identified, it is recommended that an onshore integration test of the system should be performed. Particular consideration should be given to interfaces and interactions that may occur between equipment especially where the individual items of equipment have been tested as stand-alone components. Prior to commencing integration testing, an assessment should be performed to validate that the system components have been supplied and tested to the project requirements.

Consideration shall be given to factors that cannot be reproduced and the consequences this may have. For example, a dry topside test at full load may cause over heating of cables in the absence of the cooling effect of sea water, requiring the test to be down rated or a shallow water test to be substituted.

It is not possible within the scope of this document to list every test that is desirable as this will depend upon the output from each individual assessment and upon the practical considerations that relate to each project. Data gathered from these tests may be used for benchmarking for future diagnostic analysis of the system. However, the following tests and assessments are offered for guidance.

7.2 Mechanical fit-up trials prior to assembly of the system

7.2.1 Validate that the critical mechanical interfaces that are to be made subsea are capable of being achieved with the equipment in the "as manufactured" condition and compare with the "as designed" condition to ensure that nothing has been overlooked.

7.2.2 Explore worst case tolerance and orientation scenarios to ensure that fit-up can be achieved under all possible conditions (for example, equipment being deployed onto mud mats).

7.2.3 Validate and test all installation, intervention and recovery tasks to ensure that they can be achieved in real site conditions

7.2.4 Ensure that access by Diver/ROV can be achieved where required and that the equipment orientations once made up do not cause interference with critical subsea intervention components (for example, subsea jumper harnesses or pipework blocking access to an ROV panel)

7.2.5 Maintain a record of mate & de-mates during assembly / stack / testing to ensure viable working life post deployment is not affected by the integration test

7.3 Control and protection system testing

7.3.1 Check and validate that the control functions and control loops function correctly.

7.3.2 Validate that the control and protection systems give the expected responses, especially during fault simulation and supply interruption.
7.3.3 Verify that there are communication links with subsea control systems and sensors
7.3.4 Verify that there are communication links with topside control systems and sensors. It is recommended that the topside control system used in the trial is the actual system (node) to be employed.
7.3.5 Verify the response of the control and protection system to a loss of communication
7.3.6 Validate the function of all alarm and trip levels for both topside and subsea control and protection systems.
7.3.7 If any control and protection system parameters have been changed to facilitate testing, ensure that they are restored to the default condition.
7.3.8 If testing identifies the requirement to alter control and protection system parameters, ensure these are recorded and that system manuals are updated and communicated to the relevant parties.

7.4 Electrical power system pre-testing checks

7.4.1 Verify that all auxiliary systems and interfaces are functioning (including auxiliary power supplies etc.)
7.4.2 Verify that all system shut-down signals are operational.
7.4.3 Validate that the communication links and hardwire signals are operational.
7.4.4 Check operation of the ASD/IBR in idle mode if applicable.

7.5 System Integration testing

7.5.1 Reproduce as closely as is practical the subsea system (both mechanically and electrically) with all its interconnecting components.
7.5.2 Electrical integrity should be validated by testing (e.g. continuity, insulation resistance etc.) prior to energization. Where the system has electrical isolation (for example an isolating transformer) consideration should be given to gaining temporary access to the isolated circuits for testing.
7.5.3 Emergency shut down operation shall be verified prior to testing.
7.5.4 Where practical this should be in the form of a shallow water test to reproduce the subsea environment.
7.5.5 ASD/IBR start/stop operation should be verified.
7.5.6 All system functions should be verified.
7.5.7 Operate the system as close as possible to real conditions. Where possible a full load test is preferred.
   a. Include transient conditions such as start-ups, shut downs, re-starts, fault trips and changes in operating state
   b. Verify trips and both high-end and low-end frequency range and trip response times
   c. Where applicable verify the start-up and the break-away torque
   d. Verify that stable operation is achieved across the frequency range up to full load. Determine the system parameters (e.g. voltage, current, power factor, THD etc.) at various frequencies and compare with expected values

e. Conduct a heat run at full load and verify that the temperature rise and operating temperature are within the prescribed limits across the system
f. Verify the response of the system to voltage fluctuations
g. Where applicable conduct a step-down transformer voltage and current feedback test

7.5.8 Where the effect of cooling from the normal seawater environment can not be reproduced, caution shall be exercised to limit the duration or reduce the effect of heating losses in the system

7.5.9 To simulate faults and test the system response, it is permitted to force the response by simulating the Input-Output signals of the control system

7.5.10 Consideration should be given to using umbilical simulators for long step-outs when driving rotating equipment from an ASD/IBR. Where operation at multiple frequencies is required, the umbilical simulator should simulate changes in the electrical response of the umbilical as a function of the fundamental frequency (e.g. electrical impedance)

7.5.11 Consideration shall be given to using a power network spectrum analyzer to determine the presence of resonant or harmonic voltages and currents in the system. Compare the results with what was expected from the analysis performed in Section 5.7

7.5.12 Where the scale of the system is too large to perform an integration test, consideration shall be given to testing at the sub-component level to validate key interfaces

7.5.13 Consideration should be given to using a motor-generator as a load to feed power back to the supply

7.5.14 Ensure that any control system parameters that have been changed during testing are returned to the required state prior to shipment offshore

7.5.15 Check all installation operations can be achieved in representative conditions

7.5.16 Check all maintenance operations can be achieved in representative conditions

7.6 Commissioning

It is not within the scope of this document to deal with all commissioning activity but the following comments are included as they relate to functioning of the electrical system.

7.6.1 Ensure that all of the control and protection system parameters have the correct settings in case any changes occurred during the integration testing stage. If any temporary changes are required to facilitate commissioning, ensure that the changes are recorded and that the system is restored to the correct settings prior to deployment

7.6.2 Where back-up systems are supplied (for example, uninterruptable power supplies) ensure that these are functioning correctly including any automated systems that facilitate switch-over

7.6.3 Where possible, commissioning should test the system over the operating frequency range prior to the introduction of hydrocarbons into the production system

8 QUALITY CONTROL

Manufacturers and service suppliers shall operate and maintain a quality system to a recognised and audited quality management standard such as ISO 9001. Careful consideration shall be given to all aspects of quality management in the qualification of prototype power system assemblies as this qualifies not only the design but the method of supply, inspection, manufacture and assembly. Any subsequent changes to any aspect could invalidate type tests. Testing must be representative of the system and arrangements and not introduce artificial situations that cannot be achieved in reality e.g. access for intervention when that is not possible subsea.

9 APPENDICES

Appendix 1 Subsea power system data sheet

Requirement	Data	Comments
General		
Purchaser Name		
System Designer Name		
Individual equipment suppliers' names and scope of supply		
Project name		
Number and type of electrical consumers (e.g Induction motor)		
Target TRL		

Requirement	Data		Comments
Choice of reference standards from Section 2	**Purchaser requirement [a]**	**System design capability [b]**	
API			
IEC			
IEEE			
Other			

Environmental data	Purchaser requirement [a]	System design capability [b]	Comments
Service design life time	_years	_years	
Maintenance interval	_years	_years	
Maximum operational water depth	_m	_m	
Rated Absolute Pressure	_Bar	_Bar	
Ambient external operating temperatures (min./max.)	_ / _ °C	_ / _ °C	
Ambient Internal operating temperatures (min./max.)	_ / _ °C	_ / _ °C	
Storage temperatures (min./max.)	_ / _ °C	_ / _ °C	
Handling temperatures (min./max.)	_ / _ °C	_ / _ °C	
Maximum storage time topside	_ days	_days	
Maximum storage time subsea (Non-operating)	_ days	_ days	

External surrounding media and concentration	Gas ( ), Fluid ( )	Gas ( ), Fluid ( )	
Internal surrounding media and concentration	Gas ( ), Fluid ( )	Gas ( ), Fluid ( )	
Types of chemicals to which the unit could be exposed and duration			
Rapid gas decompression rate	_Bar/min	_Bar/min	
Maximum landing speed and shock	_m/s _g	_m/s _g	
Inclination to the horizontal at installation	_º	_º	
Marine growth % of weight and % reduction in cooling	_% / _%	_% / _%	
Seismic loading capability for each of the three major axes (acceleration and duration)	X-X _g / _ s Y-Y _g / _ s Z-Z _g / _ s	X-X _g / _ s Y-Y _g / _ s Z-Z _g / _ s	
Heat exchanger fitted (Yes/No)			
Cathodic Protection Arrangement			
Special storage, transport or handling requirements			
Electrical parameters	**Purchaser requirement [a]**	**System design capability [b]**	**Comments**
Rated Power	_kW / _hp	_kW / _hp	
Power factor	_%	_%	
Rated voltage, *Un/Um*	_ kV / _kV	_ kV / _kV	See Tables 4-1 a-c
Tolerance on operating voltage	± _ %	± _ %	
Voltage unbalance tolerance (IEC61000-2-4)	Class _	Class _	
Voltage positive/negative sequence	_ %	_ %	
DC voltage component	_ V d.c.	_ V d.c.	
Induced voltage	_ V	_ V	
Full Load Current (RMS, symmetrical) when submerged at maximum operating temperature	_ A RMS	_ A RMS	
Starting current	_ A RMS	_ A RMS	

Rated frequency range	_Hz	_Hz	
Supply frequency variations	± _ %	± _ %	
Supply frequency transient recovery time	_ s	_ s	
Short circuit current rating (kA RMS symmetrical and duration)	_kA, _ms	_kA, _ms	
Umbilical cable voltage drop %	%	%	
Power supply type (e.g. ASD/IBR/DOL)			
Duty Cycle Type (IEC 60034-1. e.g. S1)	S_	S_	
Breakaway torque for motor loads	kNm	kNm	Define % margin as per Sec 4.2
Efficiency	_%	_%	
Rated Insulation level	_ kV	_ kV	
Maximum dv/dt	_kV/µs	_kV/µs	
Voltage transient recover time	_ s	_ s	
Insulation Thermal class	_ °C	_ °C	
Thermal rating of the system (amp-hours) submerged at maximum operating temperature	_Ah	_Ah	
Thermal rating of the system (amp-hours) in air at 20°C	_Ah	_Ah	
Total Harmonic Distortion	_ %	_ %	
Earthing arrangement description			
Main Earth Reference point and description of connections			
Maximum earth fault current and duration	_ kA for _ s	_ kA for _ s	
Continuous earth fault tolerance required (Yes/No)			
Duration that an earth fault can be tolerated (_ hours or continuous)			
Earthing method (Resistance/Reactance/Solid/Ungrounded)			
Number of shut down and restarts per hour			
System protection requirements			

Tolerable supply interruption duration	_ s	_ s	
Material compatibility	**Purchaser requirement [a]**	**System design capability [b]**	**Comments**

Mechanical parameters	**Purchaser requirement [a]**	**System design capability [b]**	**Comments**

Instrumentation Requirements	Purchaser requirement [a]	System design capability [b]	Comments
Temperature detector type			
Temperature detector locations			
Vibration detector type			
Vibration detector locations			
Pressure sensor type			
Pressure sensor locations			
Other instrumentation			
Other performance or test data			

Integration test requirements & duration (Section 7)	Purchaser requirement [a]	System design capability [b]	Comments

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