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# Medium Voltage Equipment Used on Subsea Production Systems

API RECOMMENDED PRACTICE 17Z  
FIRST EDITION, XXXX 202X

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## **Table of Content**

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## 1. Scope

This Recommended Practice is applicable to the design, fabrication, testing, installation and operation of Subsea Power Systems. Both single phase and three phase systems in the 7.2kVac – 69kVac (based on current developments) range will be included.

It covers subsea installed electrical power equipment and the connections between the various units.

At this time this Recommended Practice will not include DC power systems, though they may be included in future revisions.

## 2. Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.”

ABS GUIDANCE NOTES ON CONTROL OF HARMONICS IN ELECTRICAL POWER SYSTEMS

API 11S5 Recommended Practice for the Application of Electrical Submersible Cable Systems

API 14F(Z) Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1 and Division 2 Locations

API 17E Specification for Subsea Umbilicals

API 17F Specification for Subsea Production Control Systems

API 17H Remotely Operated Tools and Interfaces on Subsea Production Systems

API 17N Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management

API 17Q Subsea Equipment Qualification – Standardized Process for Documentation

IEC Guide 118 Inclusion of energy efficiency aspects in electrotechnical publications

IEC Guide 119 Preparation of energy efficiency publications and the use of basic energy publications and group energy efficiency publications

IEC 60038 Standard Voltages

IEC 60287 Electric Cables – Calculation of the Current Rating

IEC 60909 Method for Calculating Short-Circuit Currents in Three-Phase A.C. Systems

IEC 61000-4 Electromagnetic Compatibility – Part 4: Testing and Measurement Techniques

IEC 61800-4 Adjustable Speed Electrical Power Drive Systems - Part 4: General Requirements - Rating Specifications for a.c. Power Drive Systems above 1 000 V a.c. and not Exceeding 35 kV

IEC 61892-6 Mobile and Fixed Offshore Units- Electrical Installations- Part 6: Installation

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IEC 62443 Industrial Automation and Control Systems Security

IEEE Std 141-1993 General methods and calculations

IEEE Std 142-2007 IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems, (IEEE Green Book)

IEEE 399-1997 Recommended Practice for Industrial and Commercial Power System Analysis

IEEE 3002.2 - 2018 Recommended Practice for Conducting Load-Flow Studies and Analysis of Industrial and Commercial Power Systems

IEEE 3002.3 - 2018 Recommended Practice for Conducting Short-Circuit Studies and Analysis of Industrial and Commercial Power Systems

IEEE 3002.7 - 2018 Recommended Practice for Conducting Motor-Starting Studies and Analysis of Industrial and Commercial Power Systems.

IEEE 3002.8 - 2018 Recommended Practice for Conducting Harmonic Studies and Analysis of Industrial and Commercial Power Systems.

IEEE 61886.2 Subsea Equipment – Part 2: Power Transformers

IEEE 1566 Standard for Performance of Adjustable Speed AC Drives Rated 375 kW and Larger

IEEE 1580 Recommended Practice for Marine Cable for Use on Shipboard and Fixed or Floating Platforms

IMCA D 045, R 015 Code of practice for the safe use of electricity underwater

ICS 7-2006 Adjustable Speed Drives

NEMA WC 50 (ICEA P-53-426); Ampacities Including Effect of Shield Losses For Single-Conductor Solid-Dielectric Power Cable, 15 kV Through 69 kV (Copper and Aluminum Conductors)

NFPA 70 National Electrical Code (NEC)

NORSOK E-CR-001 NORSOK Standard, "Electrical Installation of Offshore Installations", E-CR-001, Rev. 3, 1997.

TIA/EIA-485-A Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems (Formerly RS-485)

### **3. Terms, Definitions, Acronyms, Abbreviations**

#### **3.1. Terms and Definitions**

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

##### **3.1.1.**

**extended factory acceptance test**

## **EFAT**

Test conducted to verify that the specified requirements, for a set of interfacing products, have been fulfilled.

### **3.1.2.**

#### **Energy efficiency**

Relates the output of an activity to its energy input, for a given service.

### **3.1.3.**

#### **life cycle**

That of a subsea development that includes design, manufacture through commissioning, operations, intervention, and decommissioning.

### **3.1.4.**

#### **predeployment test**

##### **PDT**

Test conducted to verify that the specified requirements, for a product that is ready for deployment, are still fulfilled.

### **3.1.5.**

#### **site received test**

##### **SRT**

Test conducted to verify that the specified requirements, for a product that has been transported from one site to another, are still fulfilled.

### **3.1.6.**

#### **Substantive change**

A change identified by the manufacturer that affects the performance of the product with regard to the product specification in the intended application or service condition.

### **3.1.7.**

#### **validation testing**

Test conducted to confirm that the requirements for a specific intended use or application of a product have been fulfilled.

### **3.1.8.**

#### **verification testing**

Test conducted to confirm that the specified requirements for a product have been fulfilled.

## **3.2. Acronyms and Abbreviations**

AC	alternating current
AUV	autonomous Underwater Vehicle
CT	current transducer
DC	direct current
EFAT	extended factory acceptance test
EMC	electromagnetic compatibility
FAT	factory acceptance test
FMECA	failure mode, effects, and criticality analysis

IR	insulation resistance
MER	main earth reference
MV	medium voltage
OEM	original equipment manufacturer
OPEX	operational expenditure
PDT	pre-deployment test
QRA	quantitative risk assessment
RAM	reliability, availability, and maintainability
ROT	remotely operated tool
ROV	remotely operated vehicle
RP	recommended practice
SIT	system integration test
SRT	site received test
SSU	subsea switchgear unit
SUTA	subsea umbilical termination assembly
TBD	to be determined
TCC	time-current characteristics
THD	total harmonic distortion
VSD	variable speed drive
VT	voltage transducer

## 4. System Requirements

### 4.1. General

During system design, the following design criteria shall be considered:

- flexibility with respect to electrical load situations (power and communication);
- robustness electrical system;
- seawater ingress and material compatibility;
- subsea intervention;
- human factors;
- lifecycle attributes, such as reliability, maintainability, manufacturability, usability, obsolescence management, and cyber-security risk assessment;
- ease of deployment;
- safety and emergency shutdown.

#### 4.1.1. Flexibility with Respect to Electrical Load Situations (Power and Communication)

The system should be built to accommodate a large variation in electrical loads to allow for flexibility regarding future expansion.

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The communication system should be built to function on both primary and backup communications (where applicable), within a large range of communications load variations. The communications systems should be robust with respect to failure modes.

#### **4.1.2. Monitoring of Water Content in Dielectric Oil**

Oil-filled and pressure-compensated units (e.g., subsea transformers, switchgear, and VSDs) shall include a sensor to monitor water ingress (or moisture content). The sensor shall indicate the water content increased over time to prevent the moisture from critically affecting the dielectric fluid properties (e.g., a severe reduction in breakdown strength).

#### **4.1.3. Subsea Intervention**

The subsea system shall be designed for cost-effective subsea intervention tasks, with respect to ROV operations.

Intervention systems may be operated by divers, ROV, ROT, AUV or other subsea vehicle. The design of subsea interfaces shall be in accordance with API 17H.

Retrievable medium voltage components should fulfill the following principles:

- Disconnection of lifting devices used during installation should be executed according to the intervention strategy. A backup system to release lifting devices may be provided.
- Minimize the amount of time the installation vessel is tethered to the equipment via lifting rigging after successful installation
- Have position indicators on all subsea intervention actuated connections
- Be installable within a defined practical weather window that is consistent with the specific type of installation equipment and vessel being used
- require a minimum number of special installation tools
- facilitate fully reversible sequential installation techniques/operations

It is recommended that retrievable medium voltage components be designed to provide the following functionality to facilitate efficient intervention:

- suitable viewing positions for observations during running, connection and operation of tools, modules and equipment
- suitable landing area and/or attachment points where it is necessary to carry out manipulative tasks
- protection for sensitive components/items on the subsea structure that can be damaged by the intervention system
- bucket(s) designed for easy replacement of acoustic transponder(s) (acoustic shielding and potential snagging should be avoided)
- easy operation of all mechanisms in accordance with the defined intervention strategy

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- any special equipment or arrangements installed on the subsea structure that requires the application of torque during an operation designed to use a dedicated torque tool and interface
- anodes and other construction details located such that they do not represent any obstruction or snagging point for the selected intervention system
- tools, modules and retrievable equipment having adequate running clearance to any part of the structure, adjacent module or equipment
- for guidelineless operations, provision of positive restrictions, such as guide funnels or bumper beams, to avoid impact between adjacent equipment

#### **4.1.4. Human Factors**

System design should take into account human factors in order to optimize the overall system performance.

#### **4.1.5. Lifecycle Attributes such as Reliability, Maintainability, Manufacturability, and Usability**

Reliability, maintainability, manufacturability, and usability are the factors that affect run-time behavior, system design, and user experience. They represent areas of concern that have the potential for applicationwide impact across layers and tiers.

#### **4.1.6. Obsolescence Management**

For information on obsolescence management, refer to API 17F.

#### **4.1.7. Cybersecurity Risk Assessment**

A risk assessment should be performed in accordance with IEC62443 Industrial Automation and Control Systems Security to assess the system's level of cybersecurity risk and preparedness.

#### **4.1.8. Safety and Emergency Shutdown**

Systems shall be designed for safe operation and be able to shut down production in a safe and efficient manner that complies with all regulatory and specified requirements.

### **4.2. Analysis Requirements**

#### **4.2.1. General**

The design and operation of MV subsea power systems require several studies to assist in the evaluation of the initial and future system performance, system reliability, safety, and potential future expandability.

The power delivery system operation under fault conditions shall be defined, and this shall be the basis for the requirements for fault detection & protections systems to be utilized.

Maximum and minimum electrical fault levels shall be calculated throughout the network with the aim to design fault detection and protection systems.

Voltage levels throughout the distribution system shall be calculated in all foreseen operating conditions (e.g. maximum and minimum load), with consideration for equipment design tolerances and tolerances on the power supply parameters of the host facility.

The studies required for MV systems are:

- a) Load Flow
  - These studies determine the voltage, current, active, and reactive power and power factor in a power system.
- b) Cable Ampacity
  - These studies calculate the current carrying capacity (ampacity) of power cable in topside and subsea installations.
- c) Short-circuit
  - These studies determine the magnitude of the potential currents flowing in a power system at various times after a fault occurs
- d) Protective Device Coordination
  - These studies determine or verify the clearing characteristics such as fuses, circuit breakers and relays used in the protective scheme. They are also needed to determine the protective device settings that will provide selective fault isolation.
- e) Stability
  - These studies determine or measure the ability of a power system, containing two or more synchronous machines, to continue to operate after a change occurs. Stability should be determined for both steady-state and transient conditions.
- f) Motor-starting
  - These studies determine speed, slip, electrical output torque, load current and terminal voltage at discrete time intervals from locked rotor to full speed
- g) Harmonic analysis.
  - This study is used to predict distortion levels caused by the addition of a new harmonic load. A harmonic study shall be performed to assess the harmonic content (THD and single harmonics) throughout the power delivery network, with the aim to investigate the presence of disturbances or resonance phenomena.
- h) Transformer analysis
  - These analyses determine design parameters associated with subsea transformers such as premagnetization, taps, etc. For details of the required analyses refer to IEC/IEEE 61886-2.
- i) Reliability
  - These studies are used to determine system reliability and availability and select an acceptable system design for subsea application. A FMECA of the fault detection & protection circuits shall be performed for MV power distribution networks. The output of the FMECA shall demonstrate that the fault mechanisms are understood, and the detection & protection mechanisms are suited to the requirements.
- j) Grounding
  - Ground fault studies is to provide for the safety and well-being of personnel that can be exposed to the potential differences that can exist in a subsea power system during a severe fault.
- k) Switching Transients
  - A transient system analysis shall be performed to assess the following conditions as a minimum:
    - transients during energisation of system
    - transients during de-energisation of system
    - transients during dynamic events (such as load switching), including all potential inrush phenomena
    - transients during fault condition
    - transient conditions following fault elimination

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Figures with specific rating information shall be generated for each project, similar to IEEE 3002.2 Figures 1-9. Figures with output data for each component shall also be generated similar to IEEE 3002.2 Figures 16, 17 & 18.

The following diagrams (Figures 4.1 to 4.4) indicate the typical subsea power systems that are currently deployed.

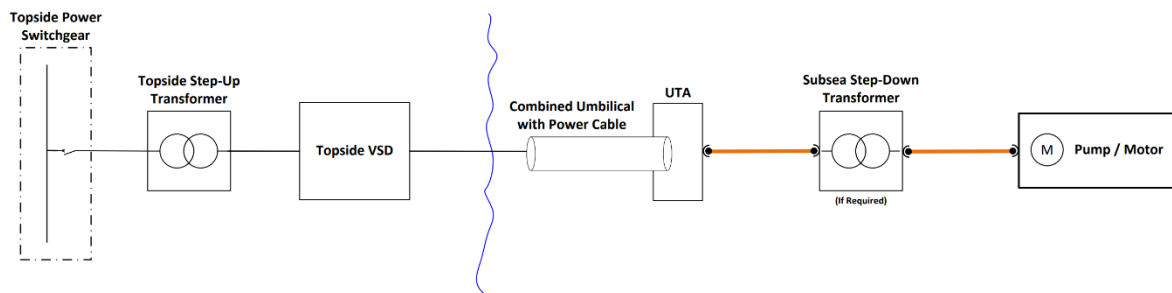


Figure 1-1 – Single Power String – Topsides VSD

#### **Figure 4.1 Single Power String – Topsides VSD**

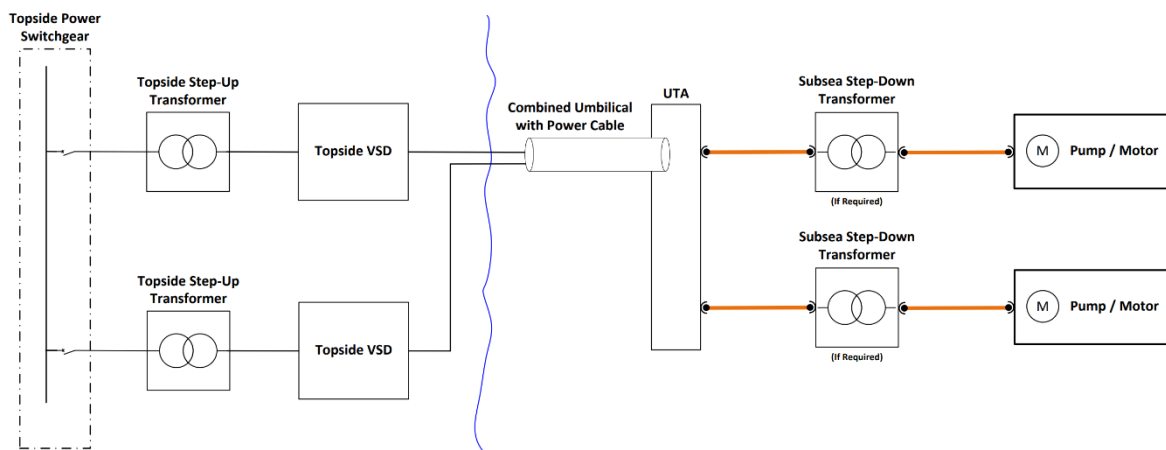


Figure 1-2 – Dual Power String – Topsides VSD

#### **Figure 4.2 Dual Power String – Topsides VSD**

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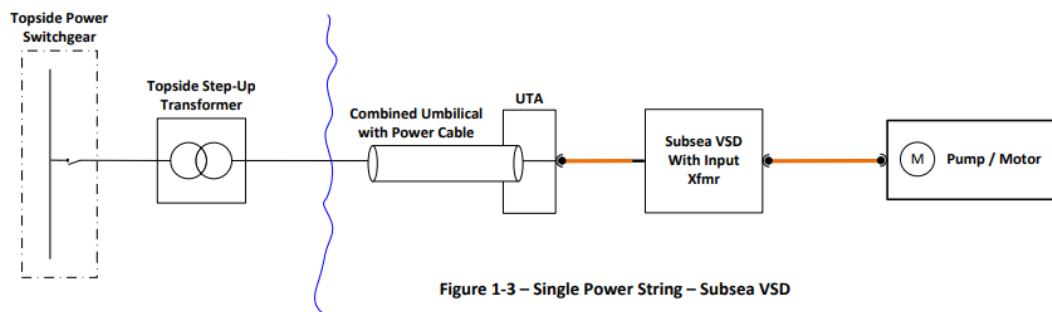


Figure 1-3 – Single Power String – Subsea VSD

### **Figure 4.3 Single Power String – Subsea VSD**

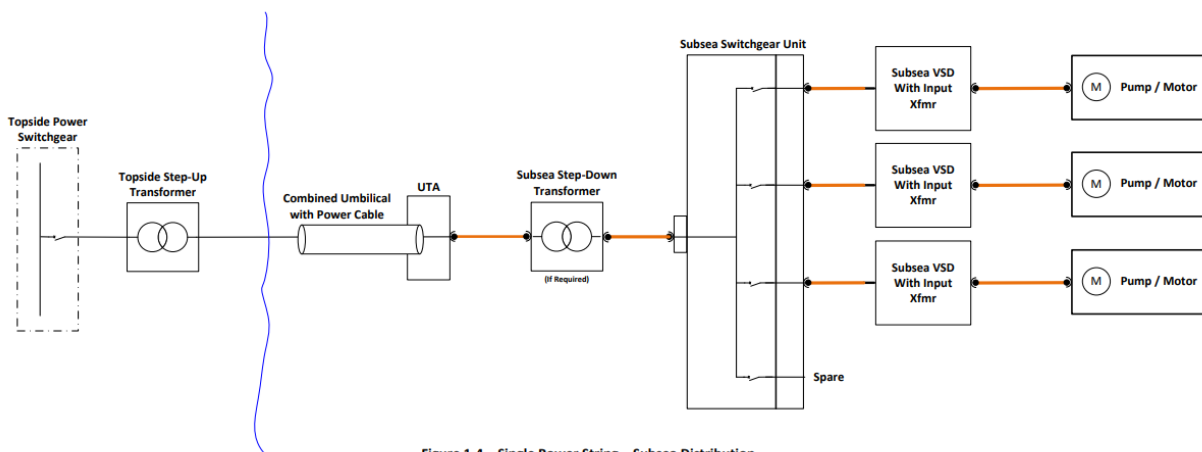


Figure 1-4 – Single Power String – Subsea Distribution

### **Figure 4.4 Single Power String – Subsea Distribution**

## **4.2.2. Load Flow Analysis**

### **4.2.2.1. General**

Load flow analysis shall be performed on the power string and/or system, to determine voltage, current, and power at each system bus, node, and branch. Such analysis is performed under steady state conditions, with various network architectures, configurations, and load cases.

Refer to IEEE 3002.2-2018 Section 3 - Introduction, for a complete load flow analysis description.

### **4.2.2.2. Input Data and Analysis Tools**

Refer to Figures 1-1 thru 1-4 for required input data for the various power system architectures. Also refer to IEEE 3002.2-2018 Section 6 - Required Input Data, for a comprehensive description of load flow analysis inputs.

Specific load flow analysis software and solution algorithms shall be as specified by the end client, or as proposed by the simulation engineer and agreed by the end client. If the end client does not have a preference, refer to IEEE 3002.2-2018 Section 12 - Features of Analysis Tools for minimum load flow simulation software requirements.

### **4.2.2.3. Analysis Objectives, Results, and Reporting**

Refer to IEEE 3002.2-2018 Section 4 - Analysis Objectives and Section 10 - Analysis of Load Flow Results and Reports.

Load flow simulations shall be performed for each disparate system architecture and configuration and shall include load cases as defined by the end client.

Results shall be reported graphically and in verbiage/table format. Such reporting, shall in general, comply with the example provided in IEEE 3002.2-2018 Section 9 - Load-Flow Study Example. Refer also, to Figures 2-1 thru 2-4 for required results data for the various power system architectures.

At a minimum, the following output data shall be included (adapted from IEEE 3002.2-2018 Section 4 - Analysis Objectives, with edits and additions).

- Steady-state bus voltages, including magnitude and phase angle.
- Current flow, indicating magnitude.
- Power flow across the system, indicating real and reactive power, and direction of flow.
- System real and reactive power losses and voltage drops.
- Real and reactive power demand and voltage drop at source coupling.
- Loading percentage, across the system, of system components (transformers, switchgear, cables, etc.)
- Performance under maximum, normal, minimum, and startup loading conditions.
- Performance under emergency conditions (post-contingency).
- Performance under various operating configurations.
- Transformer tap settings and load tap changer requirements, if relevant.
- Requirement for either fixed or variable power factor improvement and/or compensation equipment.
- Generator exciter/regulator voltage set points, if present in system.
- Undervoltage and overvoltage conditions for buses as well as equipment terminals.
- Power factor (or phase angle between current and voltage)

#### **4.2.3. Cable Ampacity**

The ampacity of a conductor depends on its ability to dissipate heat without damage to the conductor or its insulation. This is a function of the insulation temperature rating, the electrical resistance of the conductor material, the ambient temperature, and the ability of the insulated conductor to dissipate heat to the surrounds.

IEC-60287 is used to establish the permissible current rating (ampacity) of a power cable. The standard contains formulas for calculating losses (ac resistance and dielectric losses), loss factors for power cable constituents (reinforcements etc.) and thermal resistances throughout the entire system (power cable, protective covering and surrounding medium).

The medium voltage should apply a standard voltage class as detailed in IEC 60038. Medium-voltage cables shall follow the basic design requirements of IEC 60502-2, which covers 3.6/6 (7.2) kV through 18/30 (36) kV, with additional consideration for submarine applications. For higher voltages, reference is made to NEMA WC 50 which covers voltage up to 69 kV.

#### **4.2.4. Protection and coordination studies**

##### **4.2.4.1. General**

Protective device selection shall be based on the protective device philosophy report. This outlines how to disconnect faulty parts of the power system effectively. This shall be prepared in conjunction with the performed power system studies.

Protective device coordination analysis shall be performed on the power system to verify that the clearing characteristics of devices such as fuses, circuit breakers and relays. These studies also inform the protective device setting that will provide effective and selective fault isolation.

##### **4.2.4.2. Input Data and Analysis Tools**

The basis for coordination analysis is a single line diagram with the following information

- Protective device manufacturer & type
- Protective device rating
- Trip setting
- Short circuit current at each system bus
- Full load current of all loads
- Voltage level at each bus
- Transformer KVA, impedance and connections
- CT & PT ratios
- Cable size, conductor material and insulation data

##### **4.2.4.3. Coordination Analysis**

The operation and coordination of protective devices shall be determined by the graphic representation of the time-current characteristics (TCC) of each device. The relationship of device characteristics can be visualized and managed using a common graph.

A TCC graph shall be required for all protective device

Reference IEE std 399 chapter 15 for details of coordination process and methods

#### **4.2.5. Harmonic Analysis**

##### **4.2.5.1. General**

Harmonic analysis shall be performed on the power system, to verify that harmonic distortions generated under all operating conditions are within specification.

Refer to IEEE 3002.8 Section 4 - Introduction, for a detailed introduction to Harmonic Analysis.

##### **4.2.5.2. Input Data and Analysis Tools**

The data required for analysis is detailed in section 9 or IEEE 3002.8

Specific Harmonic analysis modelling software shall be as specified by the end client, or as proposed by the simulation engineer and agreed by the end client.

##### **4.2.5.3. Analysis Objectives, Results, and Reporting**

A harmonic study report for the system shall be produced. The report shall include the topics detailed in IEEE 3002.8 Section 6 - section 14.2.

The following shall be documented:

- Harmonic distortion spectrum for each distortion source
- Plot of the system impedance as function of frequency as seen from the harmonic sources
- Calculate harmonic current amplifications at parallel resonance frequencies
- Calculate harmonic voltage amplifications at series resonance frequencies
- Document that equipment is dimensioned to withstand harmonic voltage and current amplifications
- Calculated harmonic currents in feeders
- Calculated THDv (in % of fundamental voltage component)
- Calculated single voltage harmonics
- Recommendation on methods of reducing the harmonic distortions (filter, series inductors etc.)

#### **4.2.6. Short-Circuit Analysis**

##### **4.2.6.1. General**

Short-Circuit analysis shall be performed on the power system, to verify that power system equipment is fully rated and that the protection devices are correctly sized to all faults to be detected and removed from the system as soon as possible.

Refer to IEEE 3002.3 Section 4 - Introduction, for a detailed introduction to Short-Circuit Analysis.

##### **4.2.6.2. Input Data and Analysis Tools**

There are two methods for calculating short-circuit and device duty using ANSI and IEC standards, and depending on which standard is used the methodology and guidelines differ. These methodologies are described in more detail in sections of IEEE 3002.3

ANSI – section 8

IEC – section 10

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Specific short-circuit analysis modelling software shall reflect the standard used.

#### **4.2.6.3. Analysis Objectives, Results, and Reporting**

A short-circuit study report for the system shall be produced the contact of the report will depend on the standard and be based on the information within IEEE 3002.3 Section 16

For ANSI standard based studies, the report shall include the Essential data parameters detailed in IEEE 3002.3 Section 16.2.1 and can also include the Optional data in section 16.2.2

For IEC standard based studies, the report shall include the Essential data parameters detailed in IEEE 3002.3 Section 16.3.1 and can also include the Optional data in section 16.3.2

#### **4.2.7. Motor-Starting Analysis**

##### **4.2.7.1. General**

Motor -Starting study shall be performed on the power system ideally prior to the motor being purchased, to verify that the motor's performance will meet requirements and that the wider power system will not be adversely affected during large motor starting which can cause adverse disturbances

Refer to IEEE 3002.7-2018 Section 4 - Introduction, for a detailed introduction to Motor-Starting Analysis.

##### **4.2.7.2. Input Data and Analysis Tools**

There are two standards for motors NEMA and IEC standards and depending on which standard determined what is contained on the name plate of the motor however NEMA tends to be more conservative than IEC.

These standards are described in more detail in section 5 of IEEE 3002.7

The information contained on the name plate form part of the input data to the Motor-Starting study along with motor type and starting methodology. Motor-Starting is impacted by other system loads and therefore the input data required to perform the study is similar to that for Load-Flow and Short-Circuit studies discussed in earlier sections of this chapter

##### **4.2.7.3. Analysis Objectives, Results, and Reporting**

A motor-starting study shall be undertaken to determine the parameters that are involved during starting for example voltage, current produced and starting times. A detailed explanation of the objectives of the motor-starting study is outlined in IEEE 3002.7 Section 6 – Analysis Objectives, for a detailed introduction to Motor-Starting Analysis

The Motor Starting study report minimum output requirements are explained in detail in IEEE 3002.7 Section 14 – Results and Reporting for a deeper insight into the reporting requirements

#### **4.2.8. Subsea Earthing philosophy**

A philosophy for Earthing shall be prepared. This document shall be a guideline and the basis for proper earthing of the subsea power system.

This document shall as a minimum include:

- Description and definition on how to establish a subsea main earth reference (MER)
- Description of how to connect power equipment enclosures to MER
- Choice of earth conductor size, earth boss dimensions, bolt sizes etc., including materials
- Handling of cable screens, dimensioning, earthing/isolating etc. (for all cables in the system, topside, subsea, umbilical).
- Cable discharging shall be addressed (for example for discharges through VTs), calculating of discharge
- time, safe operation of earthing switches as a function of discharge time etc.
- Tolerance of system to ground fault – definition of expected action in the event of ground fault detection. Levels of insulations resistance at which protection actions are taken. With reference to IEC 60502-1 system categories.
- Calculated voltages and currents at locations within the system in the event of different ground fault scenarios (e.g. single conductor to ground, multiple conductors to ground etc.)

### **4.3. General Requirements**

#### **4.3.1. Service Condition – Suitability for Working Environment**

The subsea system shall be designed and operated with consideration for the external environment. For surface facilities, this includes climatic conditions, corrosion, marine growth, tidal forces, illumination, and hazardous-area classifications. For the subsea environment, this includes corrosion, ambient pressure and temperature, marine growth, fouling and boring by marine life, fishing activity or marine operations, currents, seafloor composition, and maintenance considerations. Suitability to the likely storage environment should be considered. This can include ultraviolet (UV) radiation, ozone, ice, sand, wind, humidity, or temperature extremes.

Product designs shall be capable of withstanding design pressure at rated temperatures without degradation, exceeding allowable stress and strain levels, or the impairment of other performance requirements for the design life of the system.

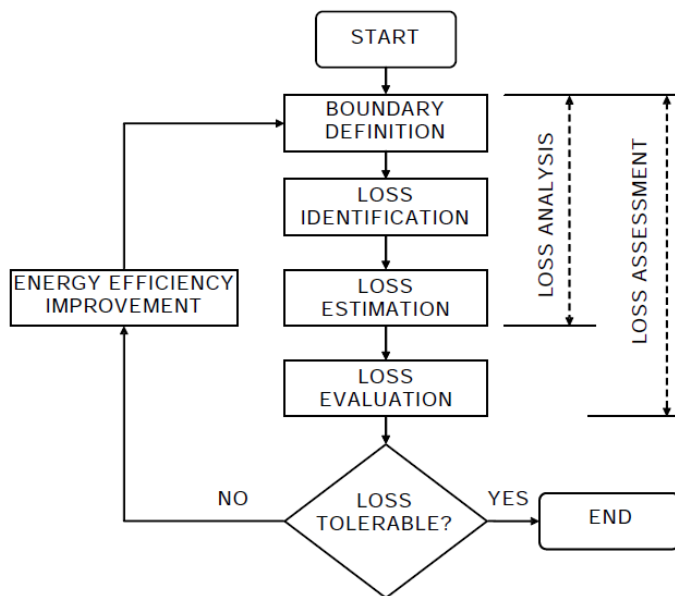
#### **4.3.2. Energy Efficiency**

The key for energy efficiency is not to reduce the given service but to optimize the energy input for a given service.

Evaluation and improvement of energy efficiency is the most cost-effective means for limiting CO<sub>2</sub> emissions, saving energy and reducing OPEX.

The key steps of such iterative process are:

- Boundary definition.
- Identification of sources of losses (loss identification)
- Estimation of losses (loss estimation)
- Evaluation of losses (loss evaluation)
- Energy efficiency improvement.



IEC

**Figure 4.9 Iterative process of energy efficiency improvement**

#### 4.3.2.1. Boundary

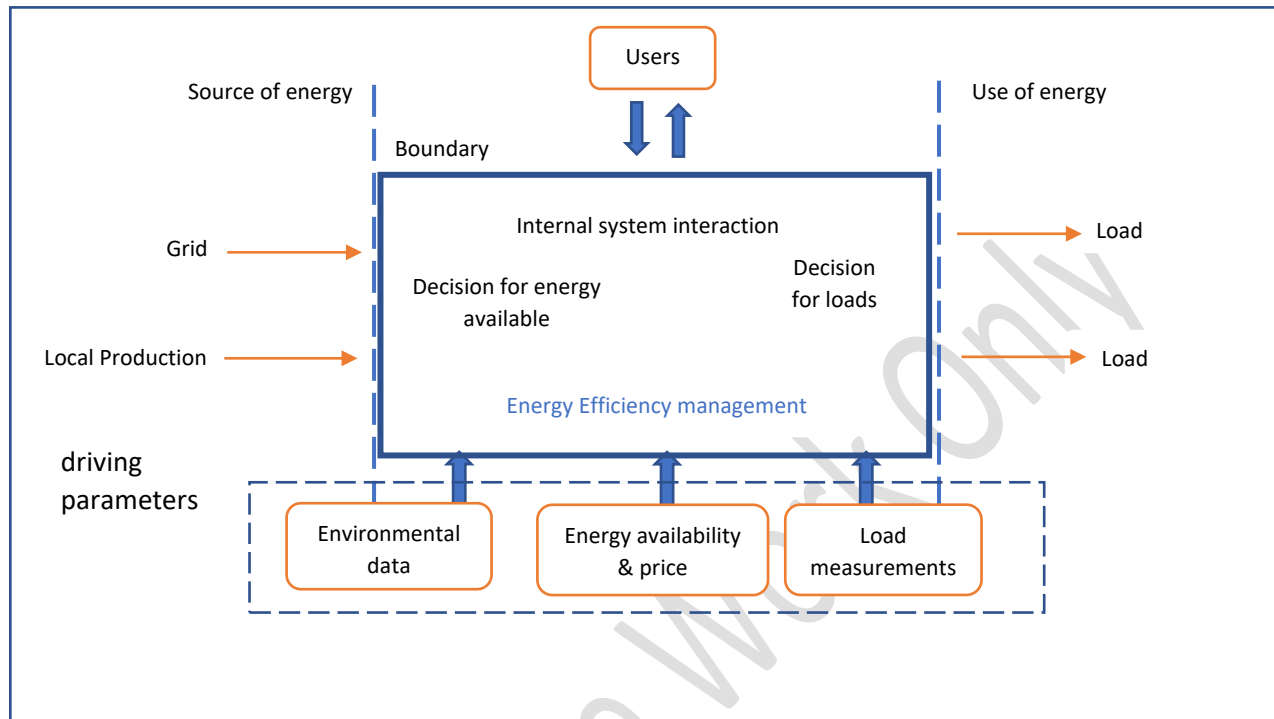
Should be defined in terms of:

- Use of energy
- Source of Energy
- Driving parameters
- Interactions between components of the system
- Possible interactions with other systems

Boundaries can include a device, a product or a system depending on the application considered.

Physical product boundaries include:

- The physical limits of the system,
- Power inputs or outputs,
- Communication interfaces,
- Any measurable inputs or outputs.



**Figure 4.10 Boundary definition**

#### 4.3.2.2. Loss Identification

The elements that have an impact (positive or negative) on energy efficiency should be identified. The first step in understanding and assessing the opportunities for improving energy efficiency is to identify where and how much is used and lost.

#### 4.3.2.3. Loss estimation

The severity of the impact (positive or negative) on energy efficiency of each source of losses identified in the previous step should be estimated.

#### 4.3.2.4. Loss evaluation

The severity of the impact (positive or negative) of losses on energy efficiency should be measured against a criterion to determine whether it is acceptable or tolerable. Based on this comparison, the need for improvement is decided.

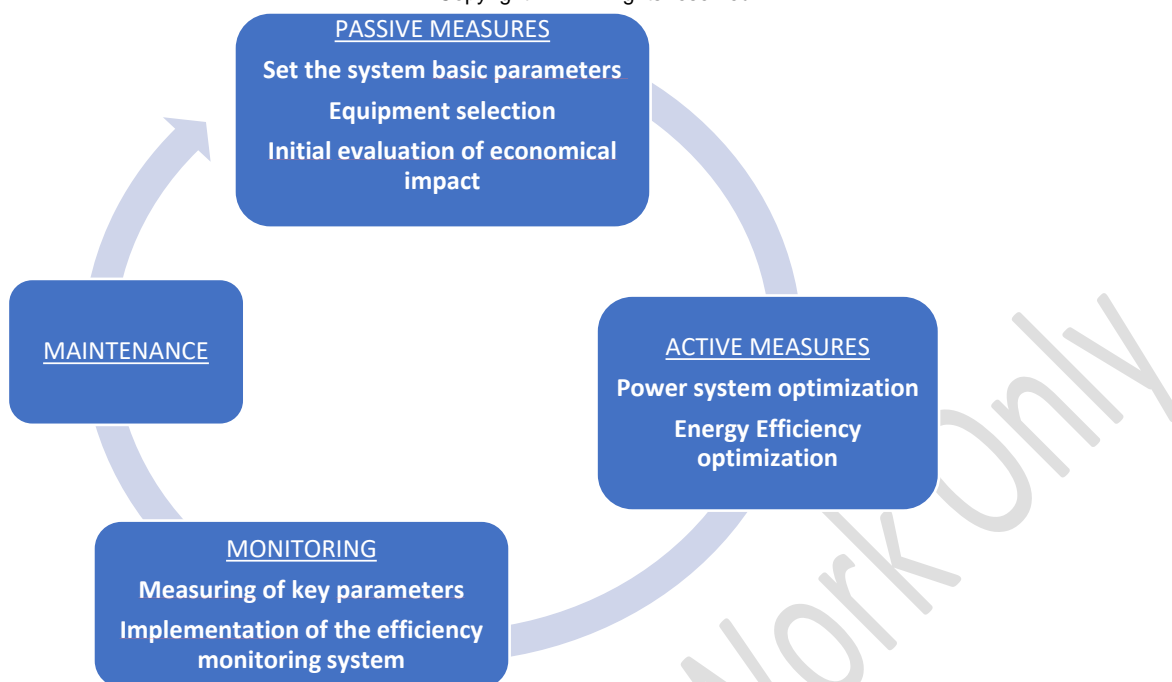
#### 4.3.2.5. Energy efficiency improvement

If the current energy efficiency level is judged to be unsatisfactory, one or more options to

improve its energy efficiency should be selected and implemented.

The energy efficiency management circle is represented in Figure 4.11

1. **Passive Measure:** Represents all the preliminary activities aimed to setup the entire power system to get a controlled efficiency within certain limits.
  - Set up of the main system parameter that can influence the choice of equipment and components such as
    - Power factor
    - V&I Harmonics
    - System Voltage
    - Frequency
    - Voltage drop
  - Equipment selection
    - Equipment temperature limits
    - Equipment sizing/working point
  - Initial evaluation of economical impact
2. **Active Measures:** Methods to be implemented to optimize the power system, distribution and energy consumption.
  - Minimizing system power losses
  - Define the Optimal Operation Voltage for Maximal Power Transfer Capability/Cable sizing
  - Minimize the number of power connectors which can introduce losses
  - Use Barycenter method to minimize cable length
  - Increasing power factor
  - Reducing current harmonics
  - Perform system simulation
3. **Monitoring:** Electrical energy efficiency key parameters should be measured and monitored to keep the system more efficient through the Implementation of a Monitoring System
4. **Maintenance**



**Figure 4.11 Energy Efficiency Measures**

## 4.4. System Requirements

### 4.4.1. Temperature Ratings—Surface-installed Equipment

#### 4.4.1.1 Without Controlled Environment

Surface-installed equipment covered by this standard that is not installed in a controlled environment shall be designed, tested, operated, and stored in accordance with the temperature and humidity requirements for the intended environment.

#### 4.4.1.2 Controlled Environment

Surface-installed equipment covered by this standard that is installed in a controlled environment shall be designed, tested, operated, and stored in accordance with the temperature and humidity ratings that are compatible with the specified controlled environment.

### 4.4.2. Temperature Ratings—Subsea-installed Equipment

Subsea-installed equipment covered by this standard shall meet or exceed the required temperature ranges described in this subsection. In Table 4.1, the test temperatures refer to pre-deployment testing environments in which the equipment may be operated (e.g., extended factory acceptance testing [EFAT], systems integration test [SIT], deck testing).

Temperature Rating— Subsea-installed Equipment	°C	(°F)
Design	-18 to 40	(0 to 104)
Test	-18 to 40	(0 to 104)

<b>Operate</b>	-5 to 40	(23 to 104)
<b>Transport/Storage</b>	-18 to 50	(0 to 122)
The temperatures relate to environment, not individual components. Subsea sensors that monitor produced or injected fluid may operate outside the ranges given and shall be rated accordingly.		

Table 4.1 Temperature ratings

#### 4.4.3. Water Depth Rating

Medium voltage components shall be qualified water depth ratings according to the guidelines described in API 17D.

The manufacturer shall demonstrate by calculation or other means that the Medium-voltage components design is suitable for the required water depth with zero internal pressure.

Hyperbaric testing (validation) shall be performed in conformance with the requirements API 17D.

Medium voltage components and assemblies are preferably tested in a hyperbaric chamber as a single unit. Components may be tested separately if the assembled unit does not fit into the hyperbaric chamber.

#### 4.4.4. Volume and Pressure Compensation

Medium voltage components may require a pressure compensating system. When a compensation system is required the compensation systems should be sized and designed in accordance with IEC-61886-2

The potential for ingress of seawater during deployment and use shall be minimized.

As a minimum, the following situations shall be reviewed:

- compensation of the oil filled subsea equipment, for retrieval or deployment;
- fluid shrinkage during cooldown;
- fluid expansion during warm-up;

#### 4.4.5. Electrical Power System

For subsea assemblies, highly reliable electrical components shall be used. Components shall be procured to industrial grade or better whenever possible.

#### 4.4.6. Communication System

The communication system shall meet or exceed the requirements of API 17F

### 5. Surface Equipment

Surface equipment should be in accordance with API14F / API 14FZ as applicable.

## **6. Subsea Equipment**

### **6.1. Design Requirements**

#### **6.1.1. Power umbilical and SUTA**

Subsea umbilicals shall be in accordance with API 17E.

#### **6.1.2. Connectors / Flying Leads**

Connectors and Power Flying Leads shall be in accordance with IEC / IEEE 61886-1.

#### **6.1.3. Transformers**

Transformers shall be in accordance with IEC / IEEE 61886-2.

#### **6.1.4. Volume compensation**

If subsea units are oil filled and pressure balanced to the seawater environment, oil volume compensation will be required in accordance with IEC / IEEE 61886-2.

## **7. Interfaces**

### **7.1. General**

The system interfaces should maintain integrity and functionality in the service conditions and take into account the following:

- internal and external pressure;
- Dielectric expansion
- seawater ingress;
- tolerance loops for interface make-up;
- internal and external temperature variations;
- protection against dropped objects and snag loading;
- Consider impact from dropped objects
- marine growth;
- Mechanical corrosion and erosion;
- scaling on subsea mate-able surfaces;
- installation / retrieval loads;
- pull-in and connection loads;
- serviceability;
- protection from subsea vehicle impact loads;
- environmental loads (currents, waves, seismic);
- subsea controls connection systems;
- chemical injection requirements / locations. (Fluid injection - e.g. barrier fluids)

Interface data sheets and outlined installation procedures for critical external interface areas should be provided. The data sheets, when implemented, should clearly describe design limitations, weights and dimensions as applicable. Areas that, as a minimum, should be covered are:

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- interfaces towards the supporting structure, including maximum footprint/envelopes, installation loads, cooling requirements
- interfaces towards marine contractor (equipment mass and size, lifting height, deck space, load capacity of tie-in points and structures, installation limitations, sea states, etc.);
- interfaces towards electrical flying leads
- interfaces with installation/retrieval systems and tooling.

## **7.2. Interfaces to Subsea Control and Monitoring Devices**

Interfaces to subsea control and monitoring devices shall be in accordance with API 17F.

## **8. Materials and Fabrication**

Subsea structures shall be manufactured in accordance with API 17P

## **9. Testing**

### **9.1. General**

All testing shall be performed with due consideration for the safety of personnel and potential damage to the surrounding area.

A comprehensive test program should be undertaken to ensure that the system performance requirements are met. Test procedures should clearly indicate acceptance criteria for each performance requirement being tested.

To record system performance and safety margins, all test reports shall include actual readings, and not simply indicate if the test passed or failed.

Testing nonconformances shall be documented and analyzed to establish the root cause.

### **9.2. Qualification Testing**

Qualification tests shall be performed to confirm the performance of the equipment at its specified design conditions and its compatibility with the environment. As an alternative to testing, the manufacturer may provide other objective evidence, consistent with documented industry practice, that the equipment performs as specified. The corresponding qualification program, which defines functional, environmental, and system tests with corresponding acceptance criteria, shall be available before the qualification tests are executed.

If novel or extrapolated technology is being used or if proven equipment is being applied in unproven or novel applications, appropriate measures to verify equipment integrity should be taken. Such measures should include the application of qualification testing to fully explore and quantify the equipment's ultimate operational limits.

Any change in vendor, material, or manufacturing process shall be identified, and a verification program proposed for review and agreement with Company prior to start of fabrication

Equipment or fixtures used to qualify designs shall be representative of production models in terms of design, dimensions, materials, and manufacturing process.

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The number of test objects required to pass qualification testing shall be dependent on the test type and shall be decided based on the need for statistically significant results and a cost-benefit evaluation.

If a product design undergoes any changes in fit, form, function, material, change in manufacturing process, or original equipment manufacturer, the supplier shall document the impact of such changes on the performance of the product. A design that undergoes a substantive change becomes a new design requiring requalification.

A change in material might not require requalification if the suitability can be substantiated by other means.

After completion of product testing, it shall be disassembled and components inspected to validate successful completion of qualification (e.g., ensuring seal integrity by validating no water ingress).

Refer to API 17N and API 17Q for additional information on reliability and qualification procedures.

### **9.3. Factory Acceptance Testing**

Factory acceptance testing of the subsea control system elements shall be performed prior to delivery. These tests shall be a sequence of verification activities from detailed manufacturing tests verifying internal functions to higher level external functions and interface tests.

Step-by-step procedures with objectives and acceptance criteria shall be available before the start of the FAT.

Any nonconformance shall be documented and analyzed to find the reason for the fail

Electrical acceptance criteria should aim to detect inherent weaknesses in components and connections, and not be limited to fitness for use

At a minimum the complete FAT should include the following:

- a) electrical power functionality and sensitivities
- b) accuracy of sensing interfaces;
- c) communication system functionality;
- d) environmental stress screening of subsea electronic equipment
- e) electrical cable insulation resistance (IR) and continuity (refer to Annex H);
- f) leak testing of applicable canisters;
- g) verification of equipment mating;
- h) continuity to sacrificial anodes

## **9.4. Testing**

### **9.4.1. General**

The objective of this section is to outline the recommended practices for verifying that the Power System for Subsea Production Systems is designed, built and installed according to the relevant specifications and that it fulfills its functional requirements. Figures 4.1 to 4.4 show different system topologies that are considered for the subsea production power system.

The power system should go through rigorous system testing that should, as practically as possible, replicate the real-life operations of the subsea production system. All equipment and sub-systems shall have gone through their respective FAT tests and EFAT tests according to the relevant standards before the integrated system test is performed. The measurements and observations from the tests shall be

documented in such a way that they can be a basis for future troubleshooting of the system when the system is installed undersea so as to be able to reduce costly intervention during any malfunctioning of the subsea part of the system.

The tests required during the system testing phase are listed below, dependent on the system topology and project specific requirements. More information about each test can be found in section 9.4.6.

- Motor start-up, start-up torque availability and direction of rotation verification (each motor)
  - This test verifies that the subsea motor starts-up according to the pre-determined starting pattern given in the motor start-up analysis.
  - It also confirms that the driven equipment is rotating in the correct direction.
- Motor stop and trip sequence verification (each motor)
  - This test verifies the various process stops and trips that are implemented in the VSD-process controller interface.
- Power system faults, alarm, and trip limit verification (each string), includes locked rotor, current/torque limit.
  - This test verifies the various protections settings are set according to the protection coordination study
- Power system voltage regulation and power quality test (each source)
  - This test verifies that the power system is operating within its performance requirements in terms of the correct cable voltage drop compensation at different speeds and load conditions, verifying the correct V/Hz relation at the motor terminal.
  - This test verifies that the power system is operating within its performance requirements in terms of required power quality along the power systems, especially at the motor terminals.
- Dynamic tests specific to the driven equipment load characteristics
  - This test verifies that the power system responds satisfactorily to the dynamic load changes induced by the mechanical load, maintaining system stability. Example: slug test.
- Power system temperature rise/thermal stability/heat run test (each string)
  - This test verifies that the power system components run continuously at their design capacity without exceeding the temperature limits on the components. To reduce the amount of time required for temperature stabilization, this test can be performed as a continuation of other tests. If available conditions on test site to not allow for proper cooling as expected in the final application, it shall be agreed between all relevant parties which measures shall be taken (reduction in test duration and/or operating point).
- Subsea voltage variation and equipment tolerance verification (for system type 2)
  - This test verifies that each subsea load (branch) in a subsea distribution will perform within its design requirements for the full range of its input voltage variation (tolerance). The input voltage variation is primarily a result of connection/disconnection of other loads/branches feeding from the same subsea node (typically subsea switchgear). Motor start-up scenarios may also induce voltage variation at the common node.

#### **9.4.2. Prerequisites for system testing**

- FAT completed for each component in the system test setup
- Cables, cable simulator, switches etc should have a HV test on them prior to system test.
- To be further discussed: HV test should also be done for transformers and motors. Insulation resistance cannot really be considered sufficient. It can be discussed how often a HV test is needed, but it should be done when things have been transported or changed (for example new terminations on cables).
- Motor insulation resistance and loop resistance test (each loop)
- Transformer insulation resistance and loop resistance test(each loop)
  - loop resistance also including point to point test to verify that system is connected according to drawings. This is extremely important for HSE!

#### **9.4.3. HSSE consideration**

- Safe Job Analysis to be performed for each test
- Test facility HSE regulations shall be followed

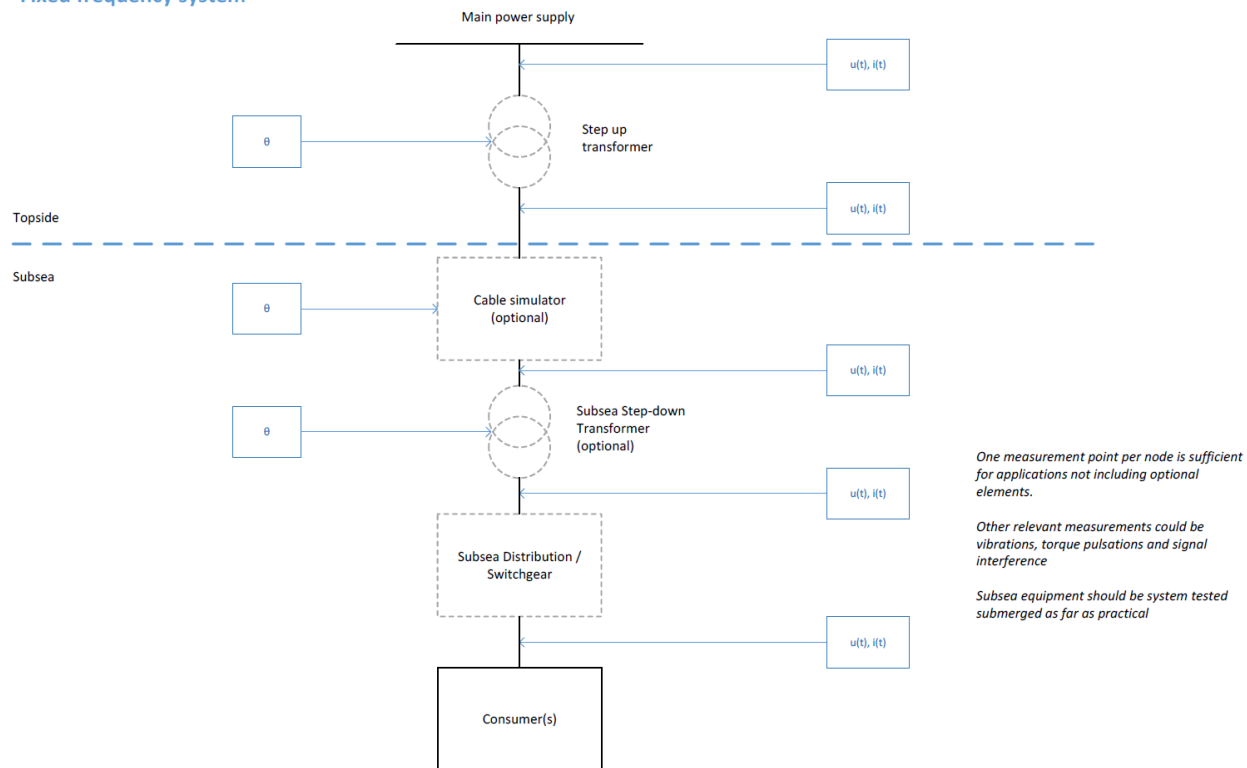
#### **9.4.4.Measurement points/parameters**

Voltage and current shall be measured at each point where significant change in voltage and current occurs (typically before and after power transformer, end of a long umbilical power cable) and where a split occurs into several parallel elements. Unless specified and agreed otherwise, phase to ground voltage measurement shall be sufficient provided that the corresponding power analyzer has sufficient software tools to extract all other relevant parameters. Line voltages shall be possible to extract from the phase-ground measurement with full sampling rate and synchronization. This means that line harmonics extracted from phase-ground measurement shall be correct.

Motor shaft speed measurement is considered optional as the subsea production application is not deemed to be speed sensitive.

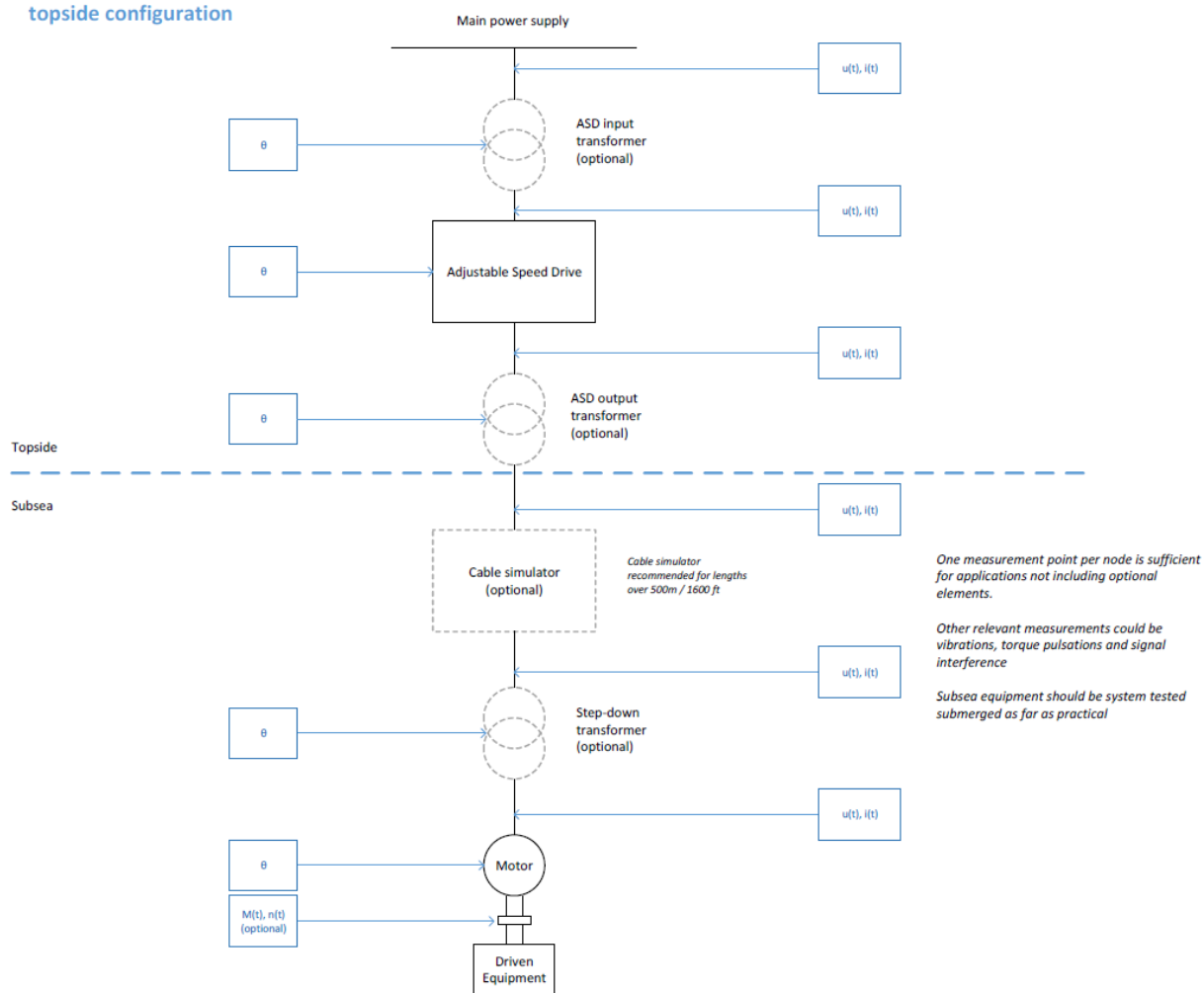
Motor vibration measurement should be considered if the driven equipment assembly is considered to require monitoring of vibration.

## Fixed frequency system

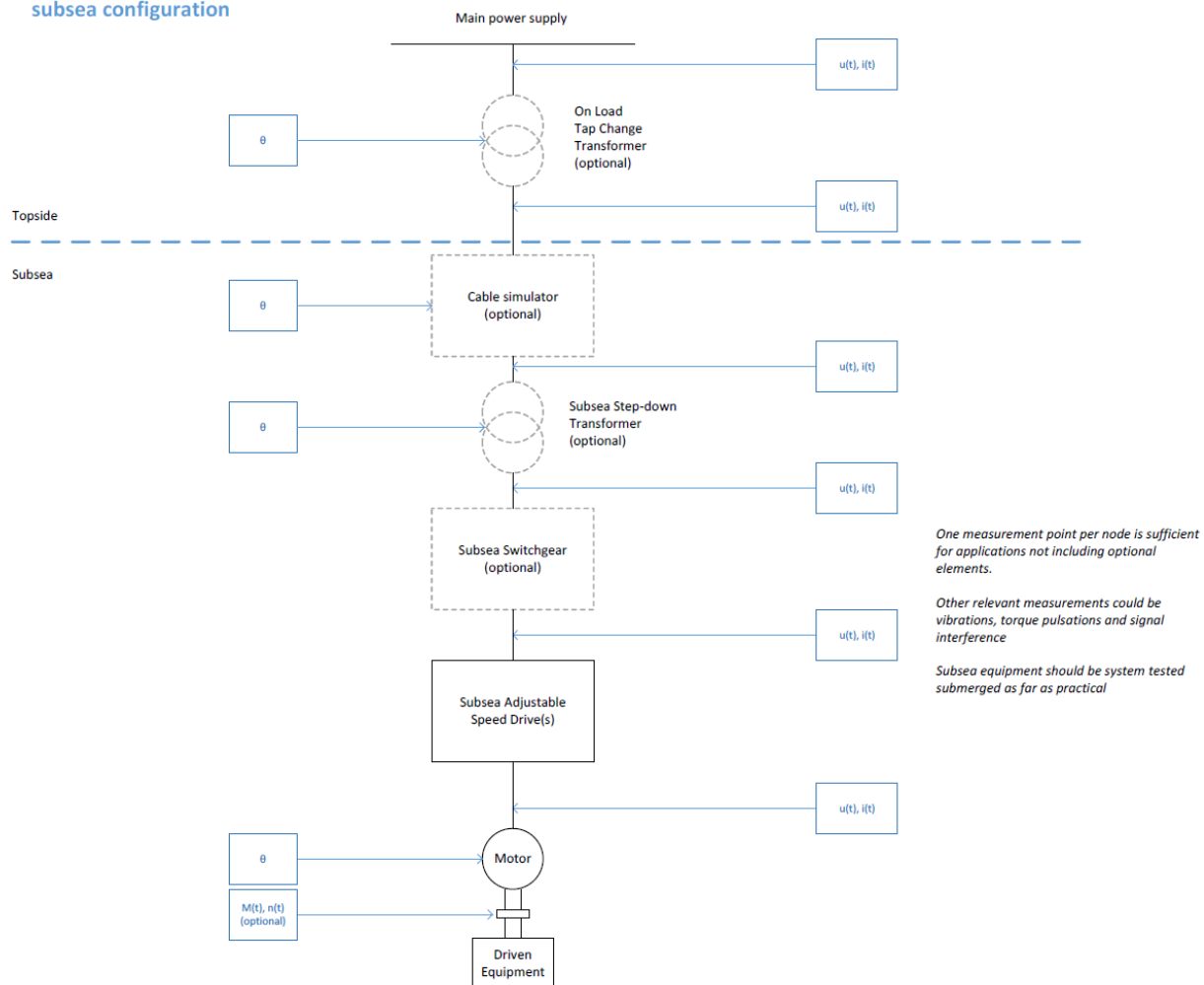


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## Adjustable frequency system, topside configuration



#### Adjustable frequency system, subsea configuration



#### 9.4.5. Test equipment

The power system test should include the complete delivery system. When delivery components are not available for system test and/or if the system test will not be practically feasible with the components (as in the case of power cables in integrated umbilical), test equipment or simulators can be used.

- Test equipment shall have, as a minimum, similar/equivalent functionalities and interfaces as the delivery component for which the test equipment is intended to replicate. Test equipment selection and use shall be agreed upon between the client and the vendor.
- Simulators shall have a reasonably accurate imitation of the equipment to be modelled. The exact accuracy shall be agreed upon between the client and the vendor. For further discussion: umbilical structures with more than one HV circuit or with HV circuit with parallel cable.

#### **9.4.6. Functional tests**

##### **9.4.6.1. Motor start-up, start-up torque availability and rotational verification (each motor)**

- Test description
  - Start-up torque availability can be done with different methods.
    1. Preferred method:

Locked rotor torque measurement at system level.
    2. Alternative 1

Reduced available starting current test. Verifies that the systems can start with margin to max current/torque.
    3. Alternative 2

Reduced available starting voltage test (field weakening at start). Verifies that the system can start with margin to max torque.
  - Complete test procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

##### **9.4.6.2. Motor stop and trip sequence verification (each motor)**

- Test description
  - Trip function should preferably be tested before startup as a “dry test”.
  - Shall also include SIL shutdowns if present.
  - Complete test procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

##### **9.4.6.3. Power system faults, alarm, and trip limit verification (each string)**

- Test description
  - This test verifies the various protections settings are set according to the protection coordination study.
  - Complete test procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

##### **9.4.6.4. Power system voltage regulation and power quality test (each source)**

- The following analysis results will be verified in these tests:
  - Steady-state bus voltages, including magnitude and phase angle.
  - Current flow, indicating magnitude.
  - Power flow across the system, indicating real and reactive power, and direction of flow.
  - System real and reactive power losses and voltage drops.
  - Real and reactive power demand and voltage drop at source coupling.
  - Power factor (or phase angle between current and voltage)

- Harmonic distortion spectrum for each distortion source. Here being specific is vital. How to measure? THD, TDR, HVF? Acceptance should be agreed in advance. Also, harmonics in electrical system may affect mechanical, so a crossdisciplined check must be performed both during analysis and testing. 1% at a certain frequency may be ok on electrical side, but catastrophic mechanically.
  - Peak values of voltage shall also be checked, as they have separate acceptance limits compared to harmonics.
  - As discussed before, we need to be careful about harmonics into the umbilical as well.
  - Calculated harmonic currents in feeders
  - Calculated THDv (in % of fundamental voltage component)
  - Calculated single voltage harmonics
  - Loading percentage, across the system, of system components (transformers, switchgear, cables, etc.)
  - Complete test procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

#### **9.4.6.5. Dynamic tests specific to the driven equipment load characteristics (e.g. slug test)**

- Test description
  - This test verifies that the power system responds satisfactorily to the dynamic load changes induced by the mechanical load, maintaining system stability. Example: slug test. It should be defined by the manufacturer and agreed with the operator.
  - Complete test procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

#### **9.4.6.6. Power system temperature rise/thermal stability/heat run test (each source/string)**

- Test description and procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

#### **9.4.7. Subsea voltage variation and equipment tolerance verification (for system type 2)**

- The following analysis results will be verified in this test:
  - Performance under emergency conditions (post-contingency).
  - Performance under various operating configurations.
  - Transformer tap settings and load tap changer requirements, if relevant.
  - Undervoltage and overvoltage conditions for buses as well as equipment terminals.
  - Complete test procedure shall be defined by the manufacturer and agreed with the operator.
- Acceptance criteria shall be defined by the manufacturer and agreed with the operator.

#### **9.4.8. Witnessing**

Tests shall be witnessed as agreed by the Operator and Equipment Manufacturer and documented in the Inspection and Test Plan.

Systems tests should be carried out in accordance with IEEE 1566 or IEC 61800-4 as appropriate

## **9.5. Documentation**

The manufacturer shall document the procedures used and the results of all performance verification tests and FATs. The documentation should identify the person(s) conducting and witnessing the tests and the time and place of the test.

## **10. Marking, Packaging, Storage and Shipping**

### **10.1. Marking**

Marking requirements for subsea systems are defined in API 17A.

### **10.2. Packaging**

#### **10.2.1. General**

Equipment shall be packaged sufficiently to prevent damage resulting from shock and vibration during transportation and storage, and also protect where necessary against thermal and ultraviolet radiation effects.

#### **10.2.2. Rust Prevention**

Before shipment, parts and equipment shall have exposed metallic surfaces (except corrosion-resistant materials and special items, such as anodes or nameplates) either protected with a rust-preventive coating that does not become fluid at temperatures of less than 50 °C (125 °F) or that is filled with a compatible fluid containing suitable corrosion inhibitors in accordance with the manufacturer's written specifications. Equipment that is already coated but shows damage after testing should undergo coating repair in accordance with the manufacturer's written specifications.

#### **10.2.3. Loose Components**

Loose components shall be packaged separately and identified as specified in 10.1.

### **10.3. Storage and Shipping**

#### **10.3.1. Elastomer Age Control**

The manufacturer shall document instructions concerning the storage environment, age control procedures, and protection of elastomeric materials.

#### **10.3.2. Electrical/Electronic Systems**

The manufacturer shall document instructions concerning storage and shipping of all electrical cables, connectors, and electronic packages.

#### **10.3.3. Crating and Handling**

For shipment, units and assemblies should be securely crated or mounted on skids to prevent damage and to facilitate sling handling.

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Shock and tilt indicators should be fitted to equipment crates and skids to provide evidence of mishandling during transport and shipping.

Protective packing material should be fixed in place over all outside mounted panel gauges to protect them from damage.

Purpose-built shipping frames should be procured for the handling and transportation of key items of subsea equipment.

#### **10.3.4. Shipping and Storage Temperature Limitations**

For shipping and storage, control system equipment should be designed and prepared to allow for the maximum expected temperature range. The fluid compensation systems may need to be replenished after exposure to high temperatures and/or transportation.

#### **10.3.5. Subsea Electrical Energy Storage Units**

Storage and handling capability shall be developed applying the following minimum criteria:

- a) Local dangerous goods regulations shall be adhered to and compliance shall be documented;
- b) Procedures for packaging, handling, storage and transportation of the subsea electrical energy storage unit, including monitoring requirements and recharge intervals, shall be submitted for Company review and approval;
- c) A declaration of conformity to UN Manual of Tests and Criteria, Sixth Revised Edition Section 38.3, Lithium metal and lithium ion batteries shall be provided.

### **11. Load-out and Installation**

Load out and installation should be in accordance with API 17A and API 17P.

### **12. Post Installation testing**

Post installation testing should be defined by the Operator and Equipment Manufacturer. As simulators may have been used during FAT / SIT actual "as installed" data should be compared with the initial analytical data and the operational data obtained during onshore testing.

### **13. Operation & Maintenance**

Operations and maintenance activities should be in accordance with API 17A.

## Bibliography

- API RP 17H Remotely Operated Vehicle (ROV) Interfaces on Subsea Production Systems
- API RP 17Q Subsea Equipment Qualification – Standardized Process for Documentation
- API RP 500 Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2
- API RP 505 Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2
- API RP 540 Electrical Installations in Petroleum Processing Plants
- DNV RP-B40 1 Cathodic Protection Design
- DNV-OS-D201 DNV Offshore Code, “Electrical Installations”, 1993.
- IEEE 45 Recommended Practice for Electrical Installations on Shipboard
- IEEE 519-1992 Standard for Harmonics
- IEEE 730 Standard for Software Quality Assurance Plans
- IEEE 1008 Standard for Software Unit Testing
- IEEE 1012 Standard for Software Verification and Validation
- IEEE 1061 Standard for Software Quality Metrics Methodology
- IEEE 1100 Recommended Practice for Powering and Grounding Electronic Equipment (IEEE Emerald Book)
- IEEE 1120 Guide for the Planning, Design, Installation, and Repair of Submarine Power Cable Systems
- IEEE 576-1989 Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry
- IEEE Std C57.12.00-2006 Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers
- IEEE Std C57.12.01-2006 Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid-Cast and/or Resin Encapsulated Windings
- IEC 60079 Electrical Apparatus for Explosive Gas Atmospheres
- IEC 60092 Electrical Installations in Ships
- IEC 60331 Tests for Electrical Cables under Fire Conditions
- IEC 60332 Tests on Electrical and Optical Fiber Cables under Fire Conditions

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IEC 60529 Degrees of Protection Provided by Enclosures

IEC 60853 Calculation of the Cyclic and Emergency Current Rating of Cables

IEC 61511 Functional Safety – Safety Instrumented Systems for the Process Industry Sector

IPC A-610D Acceptability of Electronic Assemblies

IMCA R 005, Rev.1 High Voltage Equipment: Safety Procedures for Working on ROVs

ISO 13628-7 Petroleum and Natural Gas Industries – Design and Operation of Subsea Production Systems - Part 7: Completion/Workover Riser Systems

ISO 13628-9 Petroleum and Natural Gas Industries – Design and Operation of Subsea Production Systems - Part 9: Remotely Operated Tool (ROT) Intervention Systems

NEMA 250 Enclosures for Electrical Equipment (1000 Volts Maximum)

NEMA S 1 Industrial Control and Systems General Requirements

NEMA MG 1 Motors and Generators

NFPA 72 National Fire Alarm Code