

GENERAL SPECIFICATION

SUBSEA SYSTEMS

GS EP SPS 141

Subsea Power Transformers

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1. Scope

This general specification is applicable to three-phase and single-phase liquid immersed subsea power transformers (including auto transformers) with at least one winding with rated voltages in the range $3.6 \leq U_m \leq 145$ kV and with rated power in the range 50 kVA to 100 MVA. The intention is to specify additional requirements that are not covered by [IEC 60076](#), [IEEE C57.12.00](#) and [IEEE C57.12.90](#).

Subsea transformers designed and tested in accordance with this specification shall fulfil both [IEC 60076](#), [IEEE C57.12.00](#) and [IEEE C57.12.90](#) with respect to performance and testing. In order to achieve this, the following philosophy has been used:

- Rated power shall be established (verified by testing) both in accordance with IEC and IEEE definitions. Only one figure (based on IEC or IEEE) shall however be on the rating plate, this shall be specified by purchaser in the contract.
- The most stringent design and test requirements are specified in this document, ensuring that both IEC and IEEE requirements are met.

For subsea transformers where no winding has a rated voltage above 1 kV, this standard may still be applicable, either as a whole or in part.

The mechanical design principles are also applicable for liquid-immersed shunt reactors.

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the effective date of this document.

Reference	Title
API 17F	Specification for Subsea Control Systems
ASTM D1141	Standard Practice for the Preparation of Substitute Ocean Water
ASTM D1298	Standard Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D1524	Standard Test Method for Visual Examination of Used Electrical Insulating Oils of Petroleum Origin in the Field
ASTM D1533	Standard Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration
ASTM D1816	Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes
ASTM D3612	Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography

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Reference	Title
ASTM D4059	Standard Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography
ASTM D971	Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method
ASTM D974	Standard Test Method for Acid and Base Number by Color-Indicator Titration
EN 1011	Welding. Recommendations for welding of metallic materials. General guidance for arc welding
EN 10204	Metallic products. Types of inspection documents
EN 14210	Determination of interfacial tension of solutions of surface active agents by the stirrup or ring method
EN ISO 15614 (All Parts)	Specification and qualification of welding procedures for metallic materials Welding procedure test – All Parts15
IEC 60076 (Parts 1; 2; 3; 5; 13; 14; 18)	Power Transformers - Parts 1; 2; 3; 5; 13; 14; 18
IEC 60085	Electrical insulation - Thermal evaluation and designation
IEC 60156	Insulating liquids. Determination of the breakdown voltage at power frequency. Test method.
IEC 60296	Fluids for electrotechnical applications - Unused mineral insulating oils for transformers and switchgear
IEC 60422	Mineral insulating oils in electrical equipment - Supervision and maintenance guidance
IEC 60475	Method of sampling insulating liquids
IEC 60814	Insulating liquids. Oil-impregnated paper and pressboard. Determination of water by automatic coulometric Karl Fischer titration
IEC 61378-1	Converter transformers - Part 1: Transformers for industrial applications
IEC 61619	Insulating liquids - Contamination by polychlorinated biphenyls (PCBs) - Method of determination by capillary column gas chromatography
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 62021 (Parts 1; 2)	Insulating liquids - Determination of acidity - Parts 1; 2
IEC 62535	Insulating liquids - Test method for detection of potentially corrosive sulphur in used and unused insulating oil

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Reference	Title
IEC 62697-1	Test method for quantitative determination of corrosive sulfur compounds in unused and used insulating liquids - Part 1: Test method for quantitative determination of dibenzylidene disulfide (DBDS)
IEEE C57.110	IEEE Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load Currents
IEEE C57.12.00	General requirements for liquid-immersed distribution, power and regulating transformers
IEEE C57.12.90	IEEE standard test code for liquid-immersed distribution, power and regulating transformers
IEEE C57.152	IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors
ISO 12103 (All Parts)	Road vehicles. Test dust for filter evaluation – All Parts
ISO 2178	Non-magnetic coatings on magnetic substrates - Measurement of coating thickness - Magnetic method
ISO 2409	Paints and varnishes - Cross-cut test
ISO 9001	Quality management systems - Requirements
NEMA ICS 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
NORSOK M-001	Materials selection
NORSOK M-601	Welding and inspection of piping
NORSOK M-710	Qualification of non-metallic materials and manufacturers - Polymers
NORSOK R-002	Lifting equipment
SEPS-SP-1001	Power connectors, penetrators and jumper assemblies with rated voltage from 3 kV ($U_{max} = 3.6$ kV) to 30 kV ($U_{max} = 36$ kV)

Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published in the applicable yearly collection.

Reference	Title
Not applicable	

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3. Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in [IEC 60076-1](#) and the following apply.

3.1 Terms and definitions

Absolute design pressure	Maximum absolute pressure that a subsea transformer can withstand and operate at worst case conditions.
Boost factor	Term used to express the magnetic flux margin of a transformer core; $BF = \left(\frac{(U/f)_{design}}{(U_r/f_r)} - 1 \right) * 100(\%)$.
Cable termination	Device fitted to the end of a cable to ensure electrical connection with other parts of the system and to maintain the insulation up to the point of connection.
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).
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.
Connector	Fully insulated termination permitting the connection and the disconnection of a cable to other equipment.
Differential design pressure	Maximum pressure difference between transformer tank inside and outside, at worst case operational conditions.
Dry mateable connector	Connector designed to be submerged in sea water, but connected/disconnected in a dry (topside/onshore) environment only.
Extended routine test	A test to which each individual transformer is subjected. The test shall be performed with all connector assemblies (that form an integral part of the subsea transformer) installed.
Penetrator	A device that enables one or several conductors to pass through a partition such as a wall or a tank, and insulates the conductors from it. The means of attachment, flange or fixing device, to the partition forms part of the penetrator. Penetrators include bulkhead mounted connector assembly components.
Pressure compensator	Device fitted to a tank that ensures that the internal medium pressure is identical or close to the ambient water pressure.
Routine test	Definition used in IEC 60076-1 applies.
Type test	Definition used in IEC 60076-1 applies. For instance, increased water depth or different type of penetrators (new interfaces) implies that new type tests shall be performed. Extent of type

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tests on previously type tested designs is subject to agreement between manufacturer and purchaser.

Wet mateable connector

Connector designed to be submerged in sea water, and can also be connected/disconnected in a submerged condition.

3.2 Abbreviated terms

ADP	Absolute Design Pressure
BF	Boost Factor
CP	Cathodic Protection
CR	Contact Resistance
DDP	Differential Design Pressure
FEA	Finite Element Analysis
IR	Insulation Resistance
PD	Partial Discharge
PI	Polarization Index
PMI	Positive Material Identification
PT	Penetrant Testing
RT	Radiographic Testing
ROV	Remotely Operated Vehicle
UT	Ultrasonic Testing

4. Service, transportation and storage conditions

4.1 Normal service conditions

The following service conditions apply:

1. Operational water depth: As specified in the project data sheet.
2. Steady state power frequency: As specified in the project data sheet.
3. Ambient water temperature range: Unless specified differently in the data sheet, the following ambient water operational temperature range shall apply: -5 to +20 °C.
4. Ambient air storage, handling and transportation temperature range: -25 to +60 °C.
5. Sea water current velocity: 0 m/s.

4.2 Transportation, handling and installation requirements

The following transportation, handling and installation requirements apply:

1. Transport acceleration: The subsea transformers shall be designed and manufactured to withstand a constant acceleration of minimum 2 g in 3 axis (in addition to the acceleration

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due to gravity in the vertical direction) without any damage, demonstrated by static force calculations based on a constant value of acceleration.

2. Maximum landing speed: 0.8 m/s.
3. Maximum impact acceleration during landing: 1 g.
4. Maximum tilting during handling and installation: 22 °.
5. Minimum inclination during operation: 3 °.
6. Shock recorders: Acceleration/shock recorders shall be installed for supervision during transport and installation up to the moment of submerging of the subsea transformer.

4.3 Storage

The subsea transformer shall be designed for minimum two year storage onshore and for minimum one year storage subsea, in addition to the specified design service lifetime. The manufacturer shall present procedure for operations, handling and preservations required for the storage period.

5. Design analyses

The subsea transformer including accessories (connector assemblies, connection chambers, compensators, ground resistors, instruments etc.) shall be subject to a design analysis covering as a minimum:

- Electrostatic, magnetic, thermal and mechanical finite element analysis, covering type tests and intended operational conditions. The analysis shall verify that the worst case design loads do not exceed electrical, magnetic, thermal or mechanical limitations for any material. The analysis shall include:
 - Worst case design loads (test, storage, handling, installation/retrieval and operation) including fault scenarios.
 - Thermal analysis. The complete transformer shall be analysed and effect of the pressure, any marine growth, calcium deposits etc. shall be taken into account. An ambient water current velocity of 0 m/s shall be used in the thermal analysis. The analysis shall be performed both at the rated power, and at the actual load power (if different) and cover as a minimum:
 - . Load-losses due to rms and harmonic currents. The calculation principle of additional losses is presented in the standard [IEC 61378-1](#) ([IEEE C57.110](#))
 - . Maximum continuous temperatures of insulating materials and winding temperature rises
 - . Maximum continuous hot spot temperature
 - . Maximum temperatures at the surface of the transformer tank and sea water
 - . The thermal analysis shall cover the complete operating range as specified in section 4.1 both with respect to temperature and water depth (pressure)
 - . Start-up conditions shall be addressed separately.
 - Possible nonlinear material properties

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- The parameters used in the thermal analysis shall be based on measured data for example for viscosity, thermal resistance etc.
- Mechanical and thermal effect of calcium deposits, marine growth and debris
- Impact of seismic activity shall be included as specified by the purchaser.
- Design analysis shall include calculations to verify suitability of the pressure compensating system. The analysis shall include test, storage, transportation, installation, retrieval and operational conditions. Any hysteresis shall be included.
- Ability to withstand short circuits. The analysis shall be performed in accordance with [IEC 60076-5](#).
- The material properties and limitations used in the analysis shall be identified and documented based on qualified, recognized and repeatable fabrication processes. This is also applicable for bonding between materials.
- Weight and sub merged weight analysis.
- Material selection.
- Description of welding, sealing and corrosion protection, including surface treatment solutions.

6. Design requirements

6.1 Design life time

The subsea transformer shall have a robust and reliable design with a minimum design life of 30 years.

6.2 Rated power

Although rated power of a transformer is defined differently in existing IEC and IEEE standards for topside transformers, a subsea transformer shall be tested only once but shall comply with the power rating of both standards. To accomplish this requirement, the transformer shall be tested at a fundamental frequency to determine the power rating of the secondary windings (in accordance with IEEE requirements) - while simultaneously obtaining the power rating of the primary windings (in accordance with IEC requirements).

While rated power shall be established both for IEC and IEEE definitions, only one nameplate shall be provided. This shall be specified by purchaser in the project data sheet.

The subsea transformer shall be capable of carrying, in continuous service, the rated power under conditions listed in section 4.1 and without exceeding the temperature rise limitations specified in section 6.9.

The temperature rise and the cooling requirements of the transformer in operation shall be determined after allowance is made for any increased losses due to harmonics, ref. [IEC 61378-1](#) and [IEEE C57.110](#).

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6.3 Highest voltage for equipment

The values of U_m for the subsea transformer shall be chosen from the standard values of the highest voltage for equipment, as defined in [IEC 60076-3](#) ([IEEE C57.12.00](#)).

6.4 Winding insulation

Winding insulation shall be uniform.

6.5 Neutral terminal

Neutral point(s) shall have uniform insulation.

The rated current of the neutral point shall be equal to the rated current of the corresponding transformer windings terminals.

6.6 Tappings

Tappings may be required for tuning of the turns ratio prior to final assembly, as specified in the project data sheet. If tappings are installed they shall be realized by means of bolted connections and shall not be changed after sealing of the transformer tank.

6.7 Penetrators and connectors

Penetrators and connectors used on the power terminals (including the neutral point connection, as applicable) shall comply with [SEPS-SP-1001](#). Penetrators and connectors for instrumentation and control purposes shall comply with [API 17F](#).

6.8 Transfer of over-voltages and transients

Unless agreed differently between purchaser and manufacturer, there shall be an electrostatic shield between high voltage and low voltage windings to prevent voltage transients being transferred due to capacitive coupling. The electrostatic shield shall be earthed.

6.9 Cooling and temperature limits guaranteed at the rated conditions

The following sub-clauses describe additional requirements compared to those stated in [IEC 60076-2](#) and [IEC 61378-1](#).

For converter transformer or in cases where additional losses are present due to harmonic currents, the requirements in [IEC 61378-1](#) ([IEEE C57.110](#)) apply.

The temperature rise limits given in Table 6-1 are valid for transformers with solid insulation designated as class 105 °C according to [IEC 60085](#), and immersed in mineral liquid or synthetic liquid with a fire point not above 300 °C. The limits are valid for both Kraft and thermally upgraded paper.

The temperature limits are applicable to continuous rated power at service conditions as specified in section 4.1 (yearly average).