BS IEC/IEEE 61886-2:2025

BSI Standards Publication

Subsea equipment

Part 2: Power transformers

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The UK participation in its preparation was entrusted to Technical Committee JPEL/18, Electrical installations of ships and of mobile and fixed offshore units.

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A list of all parts in the IEC/IEEE 61886 series, published under the general title *Subsea equipment*, can be found on the IEC website.

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INTRODUCTION

Use of electrical power on the seabed is increasing. Both within the oil and gas and renewable industries, there is an increasing use of electrical power equipment on the seabed. Subsea processing activities like compression and pumping require an increasingly higher amount of electrical power. Power generation, whether onshore or offshore, requires development of equipment both for subsea transmission and distribution.

This document includes requirements related to equipment installed below the sea surface. The objective of this document is to substitute project/client specific specifications.

Use of this document will avoid increased costs and schedule impact (for type testing) and reduce risk for failure. By standardizing tests and implementing continuous improvement on fewer products, this risk will be reduced in the long term.

The SEPS JIP (Subsea Electrical Power Standardization Joint Industry Project) was established in 2010 by seven oil and gas companies, with the aim to develop common operator standards for subsea electrical power equipment and systems and support further development of these into internationally recognized standards. This document proposal is developed by SEPS. The aim for the SEPS JIP is to develop IEC/IEEE dual logo standards; hence both IEC and relevant IEEE standards are referenced where applicable. Relevant equipment manufacturers have contributed with review and comments to the document.

The lack of accessibility (for repair/replacement) defines strict requirements to reliability, beyond what is normally seen in topside applications.

As subsea equipment is in many cases interconnected to topside equipment, specifications for subsea equipment are considered to be within the Scope of IEC Technical Committee 18.

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1 Scope

This part of IEC/IEEE 61886 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 ≤ U_m ≤ 245 kV and with rated power in the range 50 kVA to 300 MVA. The intention is to specify additional requirements that are not covered by the IEC 60076 series and IEEE Std C57.12™ series.

It is the intention of this document that subsea power transformers be designed and tested either in accordance with the IEC 60076 series (IEC profile) or with the IEEE C57.12 series (IEEE profile).

For subsea transformers where no winding has a rated voltage above or equal to 3,6 kV, this document can be applicable, either as a whole or in part.

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

Where the terms "subsea transformer" or "transformer" are used, this means "transformer assembly". Where required, it is stated whether transformer accessories like penetrators and connectors are included or not.

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 amendments) applies.

IEC 60076-1:2011, *Power transformers - Part 1: General*

IEC 60076-2:2011, *Power transformers - Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3:2013, *Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air*
IEC 60076-3:2013/AMD1:2018

IEC 60076-5, *Power transformers - Part 5: Ability to withstand short circuit*

IEC 60076-10, *Power transformers - Part 10: Determination of sound levels*

IEC 60076-14, *Power transformers - Part 14: Liquid-immersed power transformers using high-temperature insulation materials*

IEC 60085, *Electrical insulation - Thermal evaluation and designation*

IEC 60137, *Insulated bushings for alternating voltages above 1000 V*

IEC 60156, *Insulating liquids - Determination of the breakdown voltage at power frequency - Test method*

IEC 60247, *Insulating liquids - Measurement of relative permittivity, dielectric dissipation factor (tan δ) and d.c. resistivity*

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IEC 60296:2020, *Fluids for electrotechnical applications - Mineral insulating oils for electrical equipment*

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 61378-1:2011, *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 62021-1, *Insulating liquids - Determination of acidity - Part 1: Automatic potentiometric titration*

IEC 62021-2, *Insulating liquids - Determination of acidity - Part 2: Colourimetric titration*

IEC 62535:2008, *Insulating liquids - Test method for detection of potentially corrosive sulphur in used and unused insulating oil*

IEC 62697-1, *Test methods for quantitative determination of corrosive sulfur compounds in unused and used insulating liquids - Part 1: Test method for quantitative determination of dibenzyldisulfide (DBDS)*

IEC/IEEE 61886-1, *Subsea equipment - Part 1: Power connectors, penetrators and jumper assemblies with rated voltage from 3 kV (U_{max} = 3,6 kV) to 30 kV (U_{max} = 36 kV)*

ISO 2178, *Non-magnetic coatings on magnetic substrates - Measurement of coating thickness - Magnetic method*

ISO 2409, *Paints and varnishes - Cross-cut test*

ISO 3452 (all parts), *Non-destructive testing - Penetrant testing*

ISO 9606 (all parts), *Qualification testing of welders - Fusion welding*

ISO 12103-1:2024, *Road vehicles - Test contaminants for filter evaluation - Part 1: Arizona test dust*

ISO 13703-2, *Oil and gas industries including lower carbon energy - Piping systems on offshore platforms and onshore plants - Part 2: Materials*

ISO 15614 (all parts), *Specification and qualification of welding procedures for metallic materials - Welding procedure test*

ISO 17636-1, *Non-destructive testing of welds - Radiographic testing - Part 1: X- and gamma-ray techniques with film*

ISO 17636-2, *Non-destructive testing of welds - Radiographic testing - Part 2: X- and gamma-ray techniques with digital detectors*

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ISO 17637, *Non-destructive testing of welds - Visual testing of fusion-welded joints*

ISO 17638, *Non-destructive testing of welds - Magnetic particle testing*

ISO 17640, *Non-destructive testing of welds - Ultrasonic testing - Techniques, testing levels and assessment*

ISO 17781, *Petroleum, petrochemical and natural gas industries - Test methods for quality control of microstructure of ferritic/austenitic (duplex) stainless steels*

ISO 17782, *Petroleum, petrochemical and natural gas industries - Scheme for conformity assessment of manufacturers of special materials*

ISO 21457, *Petroleum, petrochemical and natural gas industries - Materials selection and corrosion control for oil and gas production systems*

IEEE Std C57.32, *Standard for requirements, terminology, and test procedures for neutral grounding devices*

IEEE Std C57.12.00-2021, *General requirements for liquid-immersed distribution, power and regulating transformers*

IEEE Std C57.12.90-2021, *IEEE standard test code for liquid-immersed distribution, power and regulating transformers*

IEEE Std C57.110-2018, *IEEE recommended practice for establishing liquid immersed and dry-type power and distribution transformer capability when supplying non-sinusoidal load currents*

IEEE Std C57.152, *IEEE guide for diagnostic field testing of fluid-filled power transformers, regulators, and reactors*

IEEE Std C57.154, *IEEE standard for liquid-immersed transformers designed to operate at temperatures above conventional limits using high- temperature insulation systems*

IOGP S-563, *Piping and Valve Components - Material Data Sheets*

API 17F, *Standard for subsea production control systems*

API RP 17N:2023, *Recommended practice on subsea production system reliability, technical risk, and integrity management*

ASME BPVC Section IX:2023, *ASME Boiler and Pressure Vessel Code, Section IX: Welding, Brazing and Fusing Qualifications*

ASME BPVC Section V:2023, *ASME Boiler and Pressure Vessel Code, Section V: Non-destructive Examination*

ASTM D971:20, *Standard test method for interfacial tension of insulating liquids against water by the ring method*

ASTM D974:22, *Standard test method for acid and base number by color-indicator titration*

ASTM D1141-98:2021, *Standard practice for preparation of substitute ocean water*

ASTM D1275-15:2015, *Standard test method for corrosive sulfur in electrical insulating liquids*

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ASTM D1298-12b:2017, *Standard test method for density, relative density, or API gravity of crude petroleum and liquid petroleum products by hydrometer method*

ASTM D1524-15:2022, *Standard test method for visual examination of used electrical insulating liquids in the field*

ASTM D1533-20, *Standard test method for water in insulating liquids by Coulometric Karl Fischer titration*

ASTM D1816-12:2019, *Standard test method for dielectric breakdown voltage of insulating liquids using VDE electrodes*

ASTM D3455-11, *Standard test methods for compatibility of construction material with electrical insulating oil of petroleum origin*

ASTM D3487-16e1, *Standard specification for mineral insulating oil used in electrical apparatus*

ASTM D3612-02:2017, *Standard test method for analysis of gases dissolved in electrical insulating oil by gas chromatography*

ASTM D4059-00(2018), *Standard test method for analysis of polychlorinated biphenyls in insulating liquids by gas chromatography*

AWS D1.1/D1.1M:2020, *Structural Welding Code - Steel*

DNV-ST-E273 2.7-3, *Portable offshore units*

DNV-RP-B401, *Cathodic protection design*

DNV-RP-F112, *Duplex stainless steel - Design against hydrogen induced stress cracking*

EN 1011 (all parts), *Welding - Recommendations for welding of metallic materials*

EN 10204, *Metallic products - Types of inspection documents*

EN 13445-5, *Unfired pressure vessels - Part 5: Inspection and testing*

EN 14210, *Surface active agents - Determination of interfacial tension of solutions of surface active agents by the stirrup or ring method*

NORSOK M-501, *Surface preparation and protective coating*

NORSOK M-601:2016, *Welding and inspection of piping*

NORSOK M-630:2020, *Material data sheets and element data sheets for piping*

NORSOK M-650, *Qualification of manufacturers of special materials*

NORSOK M-710:2014, *Qualification of non-metallic materials and manufacturers - Polymers*

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3 Terms, definitions, abbreviated terms and symbols

For the purposes of this document, the terms and definitions given in IEC 60076-1 and the following apply.

ISO, IEC and IEEE maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://dictionary.ieee.org

3.1 Terms and definitions

3.1.1
auxiliary chamber
chamber where components other than active parts can be installed (NGR, accessories, instrumentation, controls)

3.1.2
boost factor
B_F
magnetic flux margin of a variable frequency transformer core expressed as the ratio between the flux density occurring at a low frequency (start) and the flux density at rated frequency of the transformer

$$B_F = \frac{B_{start}}{B_r} = \frac{\frac{U_{start}}{f_{start}}}{\frac{U_r}{f_r}}$$

where

U_{start} is the start voltage based on resistive voltage drop, occurring at low frequency when the inductive voltage drop is negligible;

f_{start} is the frequency corresponding to U_{start};

B_r is the rated flux density;

B_{start} is the flux density at U_{start}

Note 1 to entry: B_F = 1 is no oversizing of the core. B_F = 2 is oversizing of core cross section of 2 times B_F = 1. In a transformer with B_F = 2, the flux density is 50 % of that in a transformer with B_F = 1.

Note 2 to entry: Boost factor is related to start-up of AC motors.

3.1.3
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

3.1.4
connection chamber
intermediate chamber between chamber for active parts and external connections

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3.1.5
connector assembly
assembly of wet and/or dry mateable connectors, penetrators, cable terminations, cable pigtails or jumper cables between subsea components, or any combination of these

3.1.6
connector
fully insulated termination permitting the connection and the disconnection of a cable to other equipment

3.1.7
differential pressure
difference between the two absolute values of pressure that are acting on either side of a wall or partition

3.1.8
dry mateable connector
connector designed to be submerged in sea water, but connected/disconnected in a dry (topside/onshore) environment only

3.1.9
extended routine test
test to which each individual transformer is subjected once all connector assemblies have been installed

3.1.10
insulation resistance
R_{it}
<for a transformer> capability of the electric insulation of a winding to resist direct current and is determined by the quotient of the applied direct voltage divided by the total current across the transformer insulation, taken at a specified time t from start of voltage application

Note 1 to entry: The voltage application time is usually 1 min (R_{i1}) and 10 min (R_{i10}); however other values can be used. Unit conventions: subscript values of 1 through 10 are assumed to be in minutes, subscript values of 15 and greater are assumed to be in seconds.

Note 2 to entry: Insulation resistance is sometimes abbreviated as IR.

3.1.11
penetrator
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

Note 1 to entry: The means of attachment, flange or fixing device, to the partition forms part of the penetrator. Penetrators include bulkhead mounted connector assembly components.

3.1.12
polarization index
$\Gamma_{t1/t2}$
quotient of the insulation resistance measured at two different times, usually t_1 = 1 min and t_{10} = 10 min after application of the direct voltage, that is an indicator of the condition of the insulation

Note 1 to entry: The insulation resistance is usually measured at 1 min (R_{i1}) and 10 min (R_{i10}); however other values can be used. Unit conventions: subscript values of 1 through 10 are assumed to be in minutes, subscript values of 15 and greater are assumed to be in seconds.

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3.1.13
pressure compensator
device fitted to a sealed transformer tank that ensures that the internal transformer liquid is pressurised by the ambient water pressure such that the differential pressure across the tank walls is maintained within the required design limits under all conditions of operation

Note 1 to entry: There is also a requirement to compensate for the volume expansion and contraction of the internal liquid due to temperature changes. As the pressure compensator is connected to the liquid volume, the pressure compensator shall be designed to accommodate this volume expansion and contraction.

3.1.14
rated absolute pressure
maximum absolute pressure that a subsea transformer has been designed to operate at under the specified conditions of use

3.1.15
rated differential pressure
maximum differential pressure that a transformer assembly has been designed to operate at under the specified conditions of use

Note 1 to entry: The rated differential pressure for a transformer assembly shall be taken as the maximum pressure difference between the tank inboard side and the outboard side.

3.1.16
routine test
test to which each individual transformer is subjected

[SOURCE: IEC 60076-1:2011, 3.11.1]

3.1.17
special test
test other than a type test or a routine test, agreed by the manufacturer and the purchaser

[SOURCE: IEC 60076-1:2011, 3.11.3, modified – Note deleted.]

3.1.18
transformer assembly
assembly consisting of transformer active parts, instrumentation, tank, volume (pressure) compensators and connector assemblies

3.1.19
type test
test made on a transformer which is representative of other transformers, to demonstrate that these transformers comply with the specified requirements not covered by the routine tests

Note 1 to entry: For instance, increased water depth or different type of penetrators (new interfaces) implies that new type tests shall be performed. Extent of type tests on previously type tested designs is subject to agreement between manufacturer and purchaser.

[SOURCE: IEC 60076-1:2011, 3.11.2, modified – Second part of the definition deleted, and notes replaced by a new note to entry.]

3.1.20
water seal
sealing element that prevents intrusion of conductive media

3.1.21
wet mateable connector
connector designed to be submerged in sea water, which can also be connected and disconnected in a submerged condition

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3.1.23
IEEE profile
iteration of this document where the user of this document follows the IEEE references

3.2 Abbreviated terms and symbols

A	area inside the saturated winding
AV	applied voltage test
ASD	adjustable speed drive
AV-R	applied voltage test – reduced level
B	magnetic core peak flux density (tesla)
B_F	boost factor
CRA	corrosion resistant alloy
f_r	rated frequency
g	acceleration of gravity
h	electrical height of winding
HV	high voltage (winding)
R_{it}	insulation resistance taken at a specified time t
IVPD	induced voltage test with partial discharge
IVW	induced voltage withstand test
K_R	Rogowski factor
LI	lightning impulse
$L_{sat\text{-}HV}$	saturated inductance, referred to HV side
MT	magnetic particle testing
N	number of turns of a winding
NGR	neutral grounding resistor (neutral earthing resistor is also a commonly used term)
PD	partial discharge
Γ	polarization index
PMI	positive material identification
PREN	pitting resistance equivalence number
PT	penetrant testing
RAP	rated absolute pressure
RDP	rated differential pressure
RT	radiographic testing
ROV	remotely operated vehicle
SFRA	sweep frequency response analysis
TRL	technology readiness level
T_{max}	highest ambient temperature the subsea transformer will experience during storage or transportation
T_{min}	lowest ambient temperature the subsea transformer will experience during storage or transportation

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U_m	highest voltage for equipment
U_r	rated voltage of a winding
UT	ultrasonic testing
WPS	welding procedure specification

4 Profiles and use of normative references

This document can be used with either IEC or IEEE normative references, but the references shall not be mixed. For the IEC profile (3.1.22), IEC references are used; for the IEEE profile (3.1.23), IEEE references are used. The purchaser shall include in the enquiry and order which normative references are to be used.

5 Service, transportation and storage conditions

5.1 Normal service conditions

The following service conditions apply.

a) Operational water depth

As specified in the data sheet.

b) Rated frequency and operational frequency range

As specified in the data sheet.

c) Ambient water temperature range

Unless specified differently in the data sheet, the following ambient water operational temperature range shall apply:

−5 °C to +10 °C

With regard to normal temperature rise requirements, the temperature at the intended installation site should not exceed 5 °C yearly average.

d) Ambient air storage, handling and transportation temperature range

Unless specified differently in the data sheet, the following temperature range shall apply:

−25 °C to +60 °C

e) Sea water current velocity:

0 m/s

NOTE Sea water speed at 0 m/s has been specified in order to ensure that this is used as the basis for thermal design.

5.2 Transportation, handling and installation requirements

Unless otherwise agreed between purchaser and manufacturer, the following requirements shall apply to the transformer assembly.

a) Basis of design

DNV 2.7-3 shall be the basis for mechanical design of the subsea transformer assembly. Unless otherwise stated in the data sheet, operational class shall be R45-Subsea. Design factor shall be minimum 2,5.

b) Transport acceleration in all directions (x-y-z):

1 g

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