Subsea power cables for wind power plants
FOREWORD

DNV GL standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.

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Any comments may be sent by e-mail to rules@dnvgl.com

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CHANGES – CURRENT

General
This is a new document.
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SECTION 1  GENERAL

1.1  Introduction

Subsea power cables account for just a small portion of the total amount of investments in offshore wind farms. However, when these power cables fail, the impact typically is very significant. In order to reduce the failure risk this standard specifies the requirements to subsea power cable installations during all phases of a subsea power cable project with a focus on evaluation of renewable energy applications in shallow water and landfall.

The objectives of this standard are to:

— support developers of wind power plants and their contractors for the application of certification. It helps to clarify requirements related to certification of subsea power cables and their accessories for offshore wind power plants
— define minimum requirements and scope for third-party evaluation of the design, manufacturing, transport, installation and operation of power cable components and projects
— provide a common platform for communicating the scope and extent of key activities during subsea power cable certification projects in renewable energy applications, e.g., with regard to approval by authorities.

Guidance note: Locally applicable regulations should be consulted to ensure that all requirements, which can be in excess of those provided in this standard, are met.

1.1.1  Scope and application

The scope and applicability of this standard are detailed in Table 1.1.

Table 1-1  Scope and application summary

<table>
<thead>
<tr>
<th>General</th>
<th>Project phases</th>
<th>Concept development, design, manufacturing, testing, storage, load-out, transport, installation, commissioning, in-service, decommissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components</td>
<td>Power cable, optical fibres, accessories such as joints and terminations, cable fixing and protection</td>
<td></td>
</tr>
<tr>
<td>Cable route</td>
<td>Termination at offshore unit, subsea route, landfall to jointing location</td>
<td></td>
</tr>
<tr>
<td>Geography</td>
<td>World-wide</td>
<td></td>
</tr>
<tr>
<td>Cable</td>
<td>Design, electrical</td>
<td>Single-core AC, three-core AC, single-core DC, bundle of two single-core DC cables, coaxial DC cables</td>
</tr>
<tr>
<td>Design, mechanical</td>
<td>Static and dynamic applications</td>
<td></td>
</tr>
<tr>
<td>Design, optical</td>
<td>With or without optical fibre package</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>No limitation</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>Up to 500 kV</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>No limitation</td>
<td></td>
</tr>
<tr>
<td>Dimensions (diameter, length)</td>
<td>No limitation</td>
<td></td>
</tr>
<tr>
<td>Water depth</td>
<td>General applicability to 100 m, application for water depths beyond 100 m with additional considerations 1)</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>Conductor</td>
<td>Copper, aluminium</td>
</tr>
<tr>
<td>Insulation</td>
<td>Extruded insulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Application for mass impregnated cables with additional considerations. Oil-filled and gas-filled cables are excluded.</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td>Method</td>
<td>No limitation</td>
</tr>
</tbody>
</table>

1) Additional considerations may e.g. be related to cable survey corridor width or cable handling equipment.
1.1.2 Alternative methods and procedures
Methods and procedures alternative to those described in this standard may be used, provided that they meet the overall objectives, safety and quality levels specified herein and are suitable for the respective application. This shall be evaluated and agreed in each individual case.

1.2 References and definitions

1.2.1 General
The following documents include provisions which, through specific reference in the text, constitute provisions of this standard essential for its application.

Where reference is made to documents other than DNV GL service documents, the valid revision shall be taken as the revision which was current at the date of issue of this standard.

1.2.2 Standards

<table>
<thead>
<tr>
<th>Standard no.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60183</td>
<td>Guide to the selection of high-voltage cables</td>
</tr>
<tr>
<td>IEC 60502</td>
<td>Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV)</td>
</tr>
<tr>
<td>IEC 60840</td>
<td>Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) - Test methods and requirements</td>
</tr>
<tr>
<td>IEC 60228</td>
<td>Conductors of insulated cables</td>
</tr>
<tr>
<td>IEC 60287-1-1</td>
<td>Electric cables - Calculation of the current rating - Part 1-1: Current rating equations (100% load factor) and calculation of losses - General</td>
</tr>
<tr>
<td>IEC 60287-2-1</td>
<td>Electric cables - Calculation of the current rating - Part 2-1: Thermal resistance - Calculation of thermal resistance</td>
</tr>
<tr>
<td>IEC 60287-3-2</td>
<td>Electric cables - Calculation of the current rating - Part 3-2: Sections on operating conditions - Economic optimization of power cable size</td>
</tr>
<tr>
<td>IEC 60300-1</td>
<td>Dependability management - Part 1: Dependability management systems</td>
</tr>
<tr>
<td>IEC 60793</td>
<td>Optical fibres</td>
</tr>
<tr>
<td>IEC 60794</td>
<td>Optical fibre cables</td>
</tr>
<tr>
<td>IEC 61400-3</td>
<td>Wind turbines - Part 3: Design requirements for offshore wind turbines</td>
</tr>
<tr>
<td>IEC 62067</td>
<td>Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) - Test methods and requirements</td>
</tr>
<tr>
<td>ISO 9001</td>
<td>Quality management systems - Requirements</td>
</tr>
<tr>
<td>ISO 13628-5</td>
<td>Petroleum and natural gas industries - Design and operation of subsea production systems - Part 5: Subsea umbilicals</td>
</tr>
<tr>
<td>ISO 14688-1</td>
<td>Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description</td>
</tr>
<tr>
<td>ISO 14688-2</td>
<td>Geotechnical investigation and testing - Identification and classification of soil - Part 2: Principles for a classification</td>
</tr>
<tr>
<td>ISO 19901-6</td>
<td>Petroleum and natural gas industries - Specific requirements for offshore structures — Marine Operations</td>
</tr>
<tr>
<td>ITU-T G.976</td>
<td>Test methods applicable to optical fibre submarine cable systems</td>
</tr>
</tbody>
</table>
1.2.3 Guidelines

Table 1-3 Overview on referenced guidelines

<table>
<thead>
<tr>
<th>Document no.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>API RP 2A</td>
<td>Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design</td>
</tr>
<tr>
<td>API RP 2RD</td>
<td>Dynamic Risers for Floating Production Systems</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 177</td>
<td>Accessories for HV cables with extruded insulation</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 279</td>
<td>Maintenance for HV cables and accessories</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 398</td>
<td>Third-party damage to underground and submarine cables</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 415</td>
<td>Test procedures for HV transition joints for rated voltages 30 kV (Um = 36 kV) up to 500 kV (Um = 550 kV)</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 476</td>
<td>Cable accessory workmanship on extruded high voltage cables</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 490</td>
<td>Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to 500 (550) kV</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 496</td>
<td>Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to 500 kV</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 560</td>
<td>Guideline to maintaining the integrity of XLPE cable accessories</td>
</tr>
<tr>
<td>CIGRE Technical Brochure 610</td>
<td>Offshore generation cable connections</td>
</tr>
<tr>
<td>CIGRE Electra 189</td>
<td>Recommendations for tests of power transmission DC cables for a rated voltage up to 800 kV</td>
</tr>
<tr>
<td>DNV-OS-H102</td>
<td>Marine Operations, Design and Fabrication</td>
</tr>
<tr>
<td>DNV-OS-H205</td>
<td>Lifting Operations (VMO Standard Part 2-5)</td>
</tr>
<tr>
<td>DNV-OS-H206</td>
<td>Loadout, transport and installation of subsea objects (VMO Standard - Part 2-6)</td>
</tr>
<tr>
<td>DNV-OS-J103</td>
<td>Design of Floating Wind Turbine Structures</td>
</tr>
<tr>
<td>DNV-RP-F401</td>
<td>Electrical Power Cables in Subsea Applications</td>
</tr>
<tr>
<td>DNVGL-RP-0360</td>
<td>Subsea power cables in shallow water</td>
</tr>
<tr>
<td>ICPC Recommendation 3</td>
<td>Criteria to be applied to proposed crossings between submarine telecommunications cables and pipelines/power cables</td>
</tr>
<tr>
<td>ICPC Recommendation 9</td>
<td>Minimum technical requirements for a desktop study (also known as cable route study)</td>
</tr>
<tr>
<td>ICPC Recommendation 11</td>
<td>Standardization of electronic formatting of route position lists</td>
</tr>
<tr>
<td>IMCA M 190</td>
<td>Guidance for Developing and Conducting Annual DP Trials Programmes for DP Vessels</td>
</tr>
<tr>
<td>IMO MSC/Circ.645</td>
<td>Guidelines for vessels with dynamic positioning systems</td>
</tr>
</tbody>
</table>

1.2.4 Terminology and definitions

Table 1-4 Definitions of verbal forms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>shall</td>
<td>verbal form used to indicate requirements strictly to be followed in order to conform to the document</td>
</tr>
<tr>
<td>should</td>
<td>verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required</td>
</tr>
<tr>
<td>may</td>
<td>verbal form used to indicate a course of action permissible within the limits of the document</td>
</tr>
</tbody>
</table>
Table 1-5 Definition of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>abandonment</td>
<td>activities associated with interrupting installation of a cable and releasing it from the cable installation vessel. Later, installation activities continue with recovery of the cable</td>
</tr>
<tr>
<td>alter course (A/C)</td>
<td>point on the cable route where the cable course changes bearing</td>
</tr>
<tr>
<td>armour (cable)</td>
<td>one or more cable covering(s) made of typically metal tape(s) or wire(s) providing tensile strength and protecting the cable from external mechanical forces, see [2.3.4.3]</td>
</tr>
<tr>
<td>array cable</td>
<td>subsea power cable connecting an offshore electricity generator with other offshore generators or an offshore substation within a project (e.g. an offshore wind farm)</td>
</tr>
<tr>
<td>as-built survey</td>
<td>survey of the installed cable system which is performed to verify the completed installation work</td>
</tr>
<tr>
<td>asset</td>
<td>term used in the context of wind farm projects to describe the project or object to be developed, manufactured and maintained. In this standard the term refers to power cables</td>
</tr>
<tr>
<td>bight</td>
<td>an S-shaped, U-shaped or Ω-shaped section of cable. Often used for a section of cable laid on the seabed during installation or hauled on board during a repair. See Figure 1-1</td>
</tr>
</tbody>
</table>

**Figure 1-1** Shapes of cable sections, top view. (a) S-shaped bight, (b) U- or Ω-shaped bight

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>bundle</td>
<td>a collection of cables stranded and fastened together, e.g. two or more AC, DC or fibre optic cables</td>
</tr>
<tr>
<td>burial</td>
<td>lowering of a cable into the ground (e.g. seabed) and providing a protective cover of soil</td>
</tr>
<tr>
<td>burial assessment study</td>
<td>cable protection study, based on hazards to the cable (fishing, shipping, dropped objects) and site conditions (soil properties, sediment mobility), to determine burial depth and suitable tools for a section of cable which meet the risk acceptance criteria. A tool capability assessment may be used to determine the likely performance including achievable burial depth</td>
</tr>
<tr>
<td>cable</td>
<td>a cable is an assembly consisting of one or more power cores with individual or common screen and sheath, assembly fillings and covered by a common protection, (see Figure 1-2). May include packages of optical fibres</td>
</tr>
</tbody>
</table>

**Figure 1-2** Typical 3-phase AC subsea power cable cross-section
### Table 1-5 Definition of terms (Continued)

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>cable engine</td>
<td>collective term for machinery used to move cables. Includes, for instance, the following:</td>
</tr>
<tr>
<td></td>
<td>— linear cable engine, with wheel pairs: Pairs of motor-driven wheels gripping a cable for pay-out or recovery. Holding force depends on the number of wheel pairs, the squeeze force acting on the cable and the friction between wheels and cable surface</td>
</tr>
<tr>
<td></td>
<td>— linear cable engine (tensioner), with tracks: Arrangement of e.g. two or four belts / tracks gripping a cable for pay-out or recovery. Holding force depends on track length, pad shape, the squeeze force acting on the cable and the friction between pads and cable surface. Also referred to as tensioner or caterpillar</td>
</tr>
<tr>
<td></td>
<td>— drum cable engine (capstan): A drum-shaped device for pay-out or recovery of a cable, used especially when large holding power is required. Fitted with a fleeting mechanism to control the position of the cable on the drum. Commonly used in conjunction with a draw off / hold back cable engine</td>
</tr>
<tr>
<td></td>
<td>— draw-off / hold-back (DOHB) cable engine: Linear cable engine used in conjunction with drum cable engines</td>
</tr>
<tr>
<td></td>
<td>— transporter: Small cable engine with typically one or two wheel pairs for moving cable</td>
</tr>
<tr>
<td>cable protection</td>
<td>any means protecting a cable from external mechanical forces</td>
</tr>
<tr>
<td>cable protection system</td>
<td>collective term for protective tubular elements which can be fitted onto a cable for mechanical protection to ensure that the cable can operate for its service life</td>
</tr>
<tr>
<td>cable route</td>
<td>path of a cable, landfall and offshore, planned or installed</td>
</tr>
<tr>
<td>cable route study</td>
<td>process of reviewing available information and identifying a safe, technically and economically viable cable route</td>
</tr>
<tr>
<td>cable system</td>
<td>a subsea power cable system may consist of cable(s), termination(s) and joint(s) Above definition applies specifically for testing of power cables. In a wider definition the cable system may also include components like hang-off, cable protection measures and optical fibres</td>
</tr>
<tr>
<td>cable tension</td>
<td>axial force on a cable. Inter-dependent with cable bending</td>
</tr>
<tr>
<td>catenary</td>
<td>a curve assumed by a cable suspended between two points, (e.g. vessel and seabed)</td>
</tr>
<tr>
<td>chinese fingers</td>
<td>sometimes also referred to as cable grip Wire mesh stocking often made from galvanized wire rope or stainless steel wire rope, specifically designed for pulling cable, strain relief or cable support</td>
</tr>
<tr>
<td>chute</td>
<td>a curved channel for passing a cable from a higher to a lower level, e.g. overboard a vessel, which does not compromise the mechanical parameters of the cable</td>
</tr>
<tr>
<td>coiling</td>
<td>simultaneous twisting and bending of a cable, one full twist per turn. If the design of the cable allows and the manufacturer confirms that a cable can be coiled, it is often referred to as coilable. Otherwise, it is referred to as non-coilable</td>
</tr>
<tr>
<td>conductor</td>
<td>part of a cable core designed for transmission of electric current, typically made of copper or aluminium</td>
</tr>
<tr>
<td>core</td>
<td>an assembly consisting of a conductor and its own electrical insulation</td>
</tr>
<tr>
<td>corridor</td>
<td>width of the area along a cable route, specified e.g. for cable route consenting, surveying purposes or post-construction exclusion zones</td>
</tr>
<tr>
<td>departure angle</td>
<td>cable, cable protection system or abandonment &amp; recovery (A&amp;R) line position with respect to the guide surface or last roller, (see Figure 4-1).</td>
</tr>
<tr>
<td>dependability</td>
<td>collective, non-quantitative term describing availability performance which is determined by reliability performance, maintainability performance and maintenance support performance see IEC 60300-1</td>
</tr>
<tr>
<td>depth of burial</td>
<td>a measure describing the lowering of a cable into the ground / seabed. Specific terms as follows apply, (see Figure 1-3):</td>
</tr>
<tr>
<td></td>
<td>— depth of trench - vertical distance between bottom of trench and undisturbed (mean) seabed level</td>
</tr>
<tr>
<td></td>
<td>— depth of lowering - vertical distance between top of cable and undisturbed (mean) seabed level</td>
</tr>
<tr>
<td></td>
<td>— depth (height) of cover - vertical distance between top of cable and average level of the backfill above top of the cable</td>
</tr>
<tr>
<td></td>
<td>Where depth of burial has not been defined specifically for a project, it should, as a default, be understood as depth of lowering defined above.</td>
</tr>
</tbody>
</table>
### Table 1-5 Definition of terms (Continued)

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>design basis</td>
<td>a set of conditions and regulatory requirements which are taken into account when designing a facility or a product</td>
</tr>
<tr>
<td>design criteria</td>
<td>the criteria applied for verification of systems, equipment, structures, etc.</td>
</tr>
<tr>
<td>design life</td>
<td>the service life of a component or system multiplied by an appropriate factor which is equal to or greater than 1</td>
</tr>
<tr>
<td>DP acceptance test</td>
<td>specific trials programme for dynamically positioned vessels covering key elements of a fault tolerant system including performance, protection and detection, meeting the requirements of the IMO equipment classes 1, 2 or 3 and/or those of the classification society. Typically carried out annually to demonstrate acceptance criteria are met and supplemented by shorter field arrival trials, see IMCA M 190.</td>
</tr>
<tr>
<td>dynamic positioning (DP)</td>
<td>a method of automatically controlling a vessel’s position and heading within certain predefined tolerances by means of active thrust. IMO MSC/Circ.645 distinguishes equipment classes 1, 2 and 3. Manual position control and automatic heading control is sometimes referred to as DP0.</td>
</tr>
<tr>
<td>earthing</td>
<td>system or process of equalising the electrical potential of conductive parts with the potential of the Earth</td>
</tr>
<tr>
<td>emergency</td>
<td>an unplanned situation where there is a high risk of (further) extensive damages and/or personnel injuries/casualties</td>
</tr>
<tr>
<td>export cable</td>
<td>subsea power cable connecting an offshore electricity generation project (e.g. an offshore wind farm) to a point to which power is delivered</td>
</tr>
<tr>
<td>fixed offshore unit</td>
<td>non-buoyant construction (e.g. offshore wind turbine, offshore substation) that is founded in the seabed (e.g. monopile, piled jacket structure) or on the seabed (e.g. gravity based structure), see e.g. IEC 61400-3, GL-IV-2 or DNV-OS-1101.</td>
</tr>
<tr>
<td>free span</td>
<td>unsupported section of a cable between two intermediate support points</td>
</tr>
<tr>
<td>generating unit</td>
<td>generating units are defined as single current generating installations like single wind turbines, tidal turbines etc. converting renewable energy sources like e.g. wind speed into electrical energy</td>
</tr>
<tr>
<td>geological study</td>
<td>collection and analysis of information about the geological history of the general area of development</td>
</tr>
<tr>
<td>ground investigation</td>
<td>a methodological approach to assess the properties of the ground (soil, rock), commonly including geological studies, geophysical surveys and geotechnical investigations. Also referred to as soil investigation</td>
</tr>
<tr>
<td>hang-off</td>
<td>a system used in offshore units to suspend a cable end through clamping. For wind farm applications armor steel wires of a subsea cable are often restrained in a steel flange welded to the interface structure.</td>
</tr>
<tr>
<td>high voltage (HV)</td>
<td>see voltage</td>
</tr>
<tr>
<td>I-tube</td>
<td>an open-ended, I-shaped section of a tube or pipe attached internally or externally to a fixed offshore unit for guiding and protection of a cable or cable assembly</td>
</tr>
</tbody>
</table>
joint accessory making a connection between two cable ends. The following types are distinguished by their application (see CIGRÉ Technical Brochure 490):

— factory joint between extrusion / manufacturing lengths under controlled factory conditions, leading to a minor increase of the outer diameter of the cable
— field joint made between two cables in the process of their installation, generally identical in design with a repair joint and treated as such
— repair joint between two cables that have been armoured; used for jointing of two delivery lengths and the repair of damaged subsea cables
— transition joint between two cables of different design (e.g. conductor material, conductor cross-section or insulation material)

The transition joint between a subsea cable and a land cable is sometimes is called sea - land transition joint.

Joints can also be distinguished by their design:

— number of power cores - single-core, three-core
— flexibility - fully flexible, flexible with some mechanical restrictions, rigid
— deployment - inline, omega (with bight)

Joints between two optical fibres are referred to as splice in this recommended practice.

J-tube an open-ended, J-shaped section of a tube or pipe, attached internally or externally to a fixed offshore unit, for guiding and protection of a cable or cable assembly

The J-tube extends from a platform deck to and inclusive of the bottom bend near the seabed. J-tube supports connect the J-tube to the supporting structure

kink a curl, twist or bend in a cable caused by tightening a looped section, which may exceed allowable mechanical limits

See Figure Figure 1-4 b

![Figure 1-4 Unintended shapes of cable sections. (a) Loop, (b) kink](image)

landfall location where the subsea cable comes on shore

lay angle angle between the longitudinal axis of a cable and the axis of a spiral wound component (e.g. armour wire)

load-out transfer of a cable from a storage facility onto a vessel, e.g. by spooling or lifting

loop unintended bow of a cable, e.g. when laid on the seabed, possibly standing, with a risk of compromising the minimum bending radius

See Figure 1-4 (a)

low voltage (LV) see voltage

maximum tensile load the largest tensile load that a cable should be subjected to, at zero curvature, without causing damage to the cable

method statement a document that gives specific instructions on how to safely perform a work related task, or operate a piece of vessel or equipment

The statement should outline all the hazards that are likely to be encountered when undertaking a task or process

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>joint</td>
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<td></td>
<td>— factory joint between extrusion / manufacturing lengths under controlled factory conditions, leading to a minor increase of the outer diameter of the cable</td>
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<td></td>
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</tr>
<tr>
<td>J-tube</td>
<td>an open-ended, J-shaped section of a tube or pipe, attached internally or externally to a fixed offshore unit, for guiding and protection of a cable or cable assembly</td>
</tr>
<tr>
<td></td>
<td>The J-tube extends from a platform deck to and inclusive of the bottom bend near the seabed. J-tube supports connect the J-tube to the supporting structure</td>
</tr>
<tr>
<td>kink</td>
<td>a curl, twist or bend in a cable caused by tightening a looped section, which may exceed allowable mechanical limits</td>
</tr>
<tr>
<td></td>
<td>See Figure Figure 1-4 b</td>
</tr>
<tr>
<td>landfall</td>
<td>location where the subsea cable comes on shore</td>
</tr>
<tr>
<td>lay angle</td>
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</tr>
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</tr>
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<td>loop</td>
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</tr>
<tr>
<td></td>
<td>See Figure 1-4 (a)</td>
</tr>
<tr>
<td>low voltage (LV)</td>
<td>see voltage</td>
</tr>
<tr>
<td>maximum tensile load</td>
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</tr>
<tr>
<td>method statement</td>
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</tr>
<tr>
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</tr>
</tbody>
</table>
Table 1-5  Definition of terms (Continued)

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum bending radius (MBR)</td>
<td>the smallest radius that a cable may be bent to, at a specific tensile load and for a specific time MBR can be assumed to mean the internal bending radius (except if specified by the manufacturer at the cable’s centre line). Conditions for which MBR applies should be stated, e.g. during storage or installation. Sometimes distinguished into static and dynamic minimum bending radii.</td>
</tr>
<tr>
<td>near shore</td>
<td>zone of the shore where waves are transformed through interaction with the seabed</td>
</tr>
<tr>
<td>offshore</td>
<td>zone beyond the near shore area</td>
</tr>
<tr>
<td>offshore unit</td>
<td>facility (fixed to the seabed) to which a cable is connected, e.g. offshore substation or offshore wind turbine.</td>
</tr>
<tr>
<td>on-bottom stability</td>
<td>ability of a subsea power cable to remain in position under lateral displacement forces due to the action of hydrodynamic loads.</td>
</tr>
<tr>
<td>out of service (cable)</td>
<td>part of a decommissioned cable system left in situ</td>
</tr>
<tr>
<td>ploughing</td>
<td>towing a plough across the seabed to (a) bury a cable or (b) open a trench</td>
</tr>
<tr>
<td>pre-lay grapnel run</td>
<td>dragging of a grapnel over the seabed prior to cable installation in order to clear debris (e.g. wires or ropes) which is lying on the seabed or buried in the very top layer of the soil.</td>
</tr>
<tr>
<td>pulling stocking / pulling grip</td>
<td>gripping device holding onto the outer surface (serving, sheath) of the cable, comprised of interwoven wires or rope and a built-in anchorage arrangement. Also referred to as chinese finger.</td>
</tr>
<tr>
<td>reef</td>
<td>ridge of rock, sand or coral that rises to or near the surface of the seabed. Natural reefs are results of abiotic processes like deposition of sand or biotic processes dominated by corals, calcareous algae, and shellfish. Artificial reefs are the result of anthropogenic activities.</td>
</tr>
<tr>
<td>reliability</td>
<td>the probability that a component or system will perform its required function without failure under stated conditions of operation and maintenance and during a specified time interval.</td>
</tr>
<tr>
<td>remotely operated vehicle (ROV)</td>
<td>a crewless, fully submersible vehicle with three-dimensional manoeuvrability that is powered by and controlled from a vessel through an umbilical. The ROV typically features a range of sensors and manipulative devices to perform a variety of tasks.</td>
</tr>
<tr>
<td>risk</td>
<td>the qualitative or quantitative probability of an accidental or unplanned event occurring, considered in conjunction with its potential consequences. In quantitative terms, risk is the probability of a failure mode occurring multiplied by its quantified consequence.</td>
</tr>
<tr>
<td>route clearance</td>
<td>removal of identified objects on or near a cable route, such as out-of-service cables, unexploded ordnance or boulders which may affect cable installation.</td>
</tr>
<tr>
<td>route position list (RPL)</td>
<td>list with coordinates, water depths, etc., typically in accordance with ICPC Recommendation 11.</td>
</tr>
<tr>
<td>routine test</td>
<td>test(s) made after manufacture on every produced component (length of cable, accessory) to demonstrate that the requirements are met.</td>
</tr>
<tr>
<td>sample test</td>
<td>test(s) made after manufacture, at a specified frequency, on samples of completed components (length of cable, accessory) to verify that the specifications are met.</td>
</tr>
</tbody>
</table>
| sand wave                         | large-scale depositional feature of the seabed, formed by the movement of sediments due to (tidal) current or wave action. Movement of sediments is divisible into:  
  — rippled rigides (small-scale bed forms with asymmetrical languard forms (produced by tidal currents) or straight crested symmetrical or asymmetrical forms (produced by waves) and  
  — mega rippled ridges (intermediate-scale bed forms, formed by waves)  
  — sand waves  
  Typically, ripples have heights of less than 0.1 m and wavelengths of less than 0.6 m; mega ripples have heights of up to 1 m and wavelengths of up to 30 m; sand waves have heights exceeding 1 m and wavelengths from 30 m to 500 m. |
| scour                             | erosion of the seabed caused by shear forces due to currents and waves, resulting in relocation of sediments. Due to up-speed effects, deep holes can form around fixed structures. |
| scour protection                  | protection against erosion of the seabed at fixed offshore structures or installed cables.                                                                                                |
### Table 1-5 Definition of terms (Continued)

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>sealing</td>
<td>technical measure to render air-tightness or water-tightness. Sealing may apply, for instance, to cable end caps (preventing humidity ingress) or subsea power cable entry into an offshore unit (limiting or preventing water exchange). Due to less than perfect mating surfaces, the effectiveness of a seal depends on factors like adhesion or compression. Specifications like watertight or airtight should be qualified, e.g. by a maximum fluid / gas exchange rate over a specified period of time.</td>
</tr>
<tr>
<td>sediment</td>
<td>particulate material broken down by weathering and erosion processes and subsequently transported. Classified by grain size or composition.</td>
</tr>
<tr>
<td>sediment transport</td>
<td>movement of sedimentary material by wind, current, wave, ice or gravity action.</td>
</tr>
<tr>
<td>service life</td>
<td>the planned time period from initial installation or use until permanent decommissioning of a component or system during which the component or system shall be capable of meeting the functional requirements.</td>
</tr>
<tr>
<td>serving</td>
<td>outer covering of cable, over the armour layer. Typically made either as a continuous tubular polyethylene sheath or of helical polypropylene roving.</td>
</tr>
<tr>
<td>sidewall pressure (SWP)</td>
<td>not a pressure, but a force exerted per unit length of cable when pulled around a bend (e.g. of storage device or in a tube). SWP = pulling force / bend radius, measured in kN/m. Sidewall pressure increases with increased pulling load and smaller bend radius. Also referred to as sidewall bearing pressure.</td>
</tr>
<tr>
<td>tensile strength</td>
<td>ability of a cable to withstand tensile loads</td>
</tr>
<tr>
<td>termination</td>
<td>connection between cable and equipment or panels, including for instance: — mechanical termination - fixing of cable armouring, e.g. by hang-off — electrical cable termination - device fitted to the end of a cable core ensuring electrical connection and maintaining the insulation — optical fibre termination - connection of optical fibres to connectors and patch panels</td>
</tr>
<tr>
<td>touch-down point</td>
<td>point where, during installation, the cable first touches the seabed.</td>
</tr>
<tr>
<td>trefoil</td>
<td>arrangement of three single cores of 3-phase AC systems in a triangular formation</td>
</tr>
<tr>
<td>trenching</td>
<td>opening of a trench for simultaneous or post-lay of a cable</td>
</tr>
<tr>
<td>type test</td>
<td>test(s) made on components (cable, accessory) to verify their properties prior to supplying them on a general commercial basis.</td>
</tr>
<tr>
<td>unexploded ordnance (UXO)</td>
<td>explosive ordnance that has or has not been primed, fused or otherwise prepared for use and which has been fired, dropped, launched, projected or placed in such a manner as to constitute a hazard to personnel or material and remains unexploded either through malfunction, design or for any other reason</td>
</tr>
<tr>
<td>vessel</td>
<td>barge, ship, tug, mobile offshore unit, crane vessel or other ship-shaped unit involved in a marine operation</td>
</tr>
<tr>
<td>voltage</td>
<td>electromotive force or potential difference expressed in volts: — low voltage (LV), &lt; 1 kV — high voltage (HV), in general ≥ 1 kV, here e.g. 33, 132, 150 or 220 kV AC</td>
</tr>
<tr>
<td>water depth</td>
<td>still water level to seabed distance. In fluid mud, a nautical depth is defined as the vertical distance between the water surface and the level where seabed characteristics reach a limit beyond which contact of a vessel’s keel causes damage or unacceptable effects on controllability. The distinction between shallow and deep water is context-specific. In this recommended practice, very shallow generally means up to 20 m water depth, shallow up to 50 m, deeper more than 50 m and deep more than 100 m.</td>
</tr>
</tbody>
</table>
1.2.5 Abbreviations and symbols

Table 1-6 Abbreviations

<table>
<thead>
<tr>
<th>Short Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/C</td>
<td>alter course</td>
</tr>
<tr>
<td>A&amp;R</td>
<td>abandonment and recovery</td>
</tr>
<tr>
<td>AC</td>
<td>alternating current</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>BSH</td>
<td>Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency, Germany)</td>
</tr>
<tr>
<td>CIGRE</td>
<td>Conseil International des Grands Réseaux Électriques (International Council on Large Electric Systems)</td>
</tr>
<tr>
<td>CPS</td>
<td>cable protection system</td>
</tr>
<tr>
<td>DC</td>
<td>direct current</td>
</tr>
<tr>
<td>DP</td>
<td>dynamic positioning, dynamically positioned</td>
</tr>
<tr>
<td>EPR</td>
<td>ethylene propylene rubber</td>
</tr>
<tr>
<td>FMEA</td>
<td>failure mode and effect analysis</td>
</tr>
<tr>
<td>GIS</td>
<td>geographical information system or gas-insulated switchgear</td>
</tr>
<tr>
<td>HAZID</td>
<td>hazard identification</td>
</tr>
<tr>
<td>HAZOP</td>
<td>hazard and operability</td>
</tr>
<tr>
<td>HV</td>
<td>high voltage</td>
</tr>
<tr>
<td>ICPC</td>
<td>International Cable Protection Committee</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>LV</td>
<td>low voltage</td>
</tr>
<tr>
<td>MBR</td>
<td>minimum bending radius</td>
</tr>
<tr>
<td>OTDR</td>
<td>optical time domain reflectometry / reflectometer</td>
</tr>
<tr>
<td>PD</td>
<td>partial discharge</td>
</tr>
<tr>
<td>ROV</td>
<td>remotely operated vehicle</td>
</tr>
<tr>
<td>RPL</td>
<td>route position list</td>
</tr>
<tr>
<td>SWP</td>
<td>sideway pressure</td>
</tr>
<tr>
<td>TDR</td>
<td>time domain reflectometry / reflectometer</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>UXO</td>
<td>unexploded ordnance</td>
</tr>
<tr>
<td>VLF</td>
<td>very low frequency</td>
</tr>
<tr>
<td>XLPE</td>
<td>cross-linked poly-ethylene</td>
</tr>
</tbody>
</table>

Table 1-7 List of symbols

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>rated voltage between two phases (V)</td>
</tr>
<tr>
<td>U₀</td>
<td>rated voltage between phase and neutral (V)</td>
</tr>
<tr>
<td>Uₘ</td>
<td>maximum voltage between two phases (V)</td>
</tr>
<tr>
<td>Uₚ</td>
<td>impulse withstand voltage (V)</td>
</tr>
</tbody>
</table>
SECTION 2 PROJECT LIFE CYCLE

2.1 General

2.1.1 Objective
This section defines the requirements for the overall design and project implementation philosophy that shall be applied by stakeholders in all phases of subsea power cable system certification projects from concept development through in-service up to decommissioning.

2.1.2 Application
This section applies to all subsea power cable systems which are planned to be designed, manufactured and installed in accordance with this standard. The integrity of subsea power cable systems shall be ensured through all phases.

The life cycle of a subsea power cable system shall be split into the following phases:

Phase I: Preliminary design [2.2] defines the site conditions, applied guidelines and standards (norm hierarchy) and conceptual design.
Phase II: Detailed design [2.3] addresses the final design ready for manufacturing. It is the result of an iterative process that initially starts with the design basis and ends with the final design.
Phase III: Manufacturing and testing Sec.3 covers the surveillance of manufacturing processes and quality assurance.
Phase IV: Load-out, transport and installation Sec.4 covers requirements of surveillance of load out, transport, installation and corresponding procedures.
Phase V: Commissioning Sec.5 involves all follow-up verification and testing after installation
Phase VI: In-service Sec.6 outlines necessary operational activities like regular inspection, repair works and condition monitoring.
Phase VII: Decommissioning Sec.7 addresses cable recovery at the end of lifetime.

2.1.3 Dependability and risk based design
Safety, environmental performance and functionality of the overall cable system can be ensured by application of dependability and risk based design methodologies. The overall cable system shall be designed based on failure consequences and their probability to demonstrate that project objectives will be met.

Guidance note:
For guidance on third party damage to underground and subsea cables, see CIGRÉ Technical Brochure 398.

2.2 Preliminary design

2.2.1 Approach
Conditions of soil and site, but also impacts on the cable assumed to come in later project stages have to be considered early in the development process. Relevant information on operational and environmental conditions, applied standards or necessary calculation techniques shall be defined and outlined in a design basis document, which constitutes the groundwork for the conceptual cable design.

2.2.1.1 Functional requirements
Functional requirements shall be defined by the purchaser / wind farm developer by detailing the performance expectations / characteristics. The cable system shall have:

— ability to meet health, safety and environmental objectives of the project
— capability to transmit power (and, if applicable, information) during the design life with the required dependability
— capability to operate under the stated envelope of environmental conditions during the design life
— capability to withstand specified design loads and load combinations (mechanical and electrical)
— capability of being stored, installed, recovered, repaired and reinstated.

### 2.2.1.2 Design basis

A design basis shall be established, detailing all boundary conditions of the cable project, which, together with the functional specifications, enables a designer to pursue the design activities. Subjects covered in a design basis may include the following:

— system overview
— terms of reference
— applicable standards and codes
— project specific requirements/client specifications
— site conditions
— technical interfaces
— manufacturing and storage aspects
— load-out, transportation and installation aspects
— operation and maintenance aspects
— decommissioning aspects.

The proposed solution shall be assessed whether it meets the design criteria or not. A range of scenarios shall be considered for the various components of a cable system, covering normal operation, but also emergency situations/loads in both temporary and permanent conditions. Industry recognized calculation tools, or proprietary tools documented to provide valid results, shall be used for design and installation analyses of the subsea cable system.

### 2.2.2 System analysis

Loads acting on parts of a cable system can be classified as functional, environmental or accidental. A load combination (i.e. a set of loads acting simultaneously), rather than single loads, frequently governs the design. The cable system shall withstand the most onerous combination of loads that can be predicted to occur simultaneously.

### 2.2.3 Conceptual design

#### 2.2.3.1 General approach

An overall design philosophy including general principles shall be established for the cable project.

A project safety and hazard review shall be initiated (see DNVGL-RP-360 Sec.2 [2.2]) and shall be based on a consistent risk management framework.

Potential failure modes, their causes and consequences shall be described in the design documentation during the conceptual design stage in order to define corresponding mitigation measures along the cable route, if required.

#### 2.2.3.2 Project layout

Cable design is highly depending on the conditions of the renewable energy project being developed. Important assumptions and applicable parameters shall be clearly described, including at least:

— overall number of turbines
— type and rating of turbine
— location of the individual turbines
— location of offshore substation or onshore grid connection.
— step-up voltage
— choice of the cable type(s)
— choice of cable route(s)
— feasibility of cable installation and burial.
2.2.3.3 Electrical system studies
Conceptual and feasibility studies of an offshore wind farm are part of the conceptual design documentation. Electrical system studies should be performed to establish basic electrical design parameters. Appropriate design of the cables within the project depends on the required service conditions, which refers to (see IEC 60183):

- operating voltage in the system
- lightning overvoltage
- system frequency, AC or DC operation
- earthing / neutral point treatment
- current-carrying capacity (normal, emergency)
- short-circuit level (symmetrical, asymmetrical) and duration.

Normal, emergency operation or other interconnection schemes specified for the wind farm shall be studied in:

- power flow simulation (static, transient, harmonics)
- short-circuit calculations.

2.2.3.4 Electrical load
Current ratings and required cross-sectional areas (e.g. by application of series IEC 60287) shall be determined considering the following aspect:

100% load factor shall be assumed for cable design. Relaxation of this requirement due to an economical point of view may be accepted after assessment of a fundamental, detailed study or investigation report concerning annual wind conditions, expected load power phases and resulting cable temperature rise at the respective project site. This has to be agreed in each individual case.

**Guidance note:**

For guidance on economical load factor determination for subsea power cables, see CIGRÉ Technical Brochure 610.

Heat accumulation due to the installation in, e.g., J-tubes, I-tubes or landfall shall be considered, too. The same applies to higher losses of pipe-type cables.

The cable shall be designed to carry the maximum current without being damaged. This shall be valid for normal operation, for low-voltage situations as well as for the defined generation of reactive power according to the rules given by the local system operator.

2.2.3.5 Cable route surveys
Ground, geophysical and geotechnical investigations shall be conducted in an early stage. Detailed data shall be obtained for the total length of the planned cable route, covering a corridor of sufficient width to provide adequate information for design of the cable route as well as installation and operation related activities. The extent of investigations outlined in DNVGL-RP-360 [3.4] shall be applied by default.

2.3 Detailed design

2.3.1 General
The detailed design phase includes all activities associated with developing the cable project up to the point prepared for manufacturing phase. It constitutes an iterative process that is based on the results of the preliminary design phase.

2.3.2 Cable system design
Detailed design of the cable system and its interfaces refers to:

- refinement of electrical system design
- ensuring that the cable system can be installed safely without jeopardizing its integrity
— determination of cable losses and thermal behaviour [2.3.3.2]
— basic cable route engineering [2.3.3.8] and protection studies [2.3.4], yielding e.g. cable lengths, burial methods and burial depths
— sea bottom stability, if applicable
— if applicable, design of crossings
— design of interface with fixed offshore units [2.3.5]
— if applicable, design of interface with the land-based power system [2.3.6].

2.3.3 Subsea power cables

2.3.3.1 Electrical specifications
Voltage, frequency, short-circuit ratings and the current-carrying capacity (or the conductor cross-section) shall be specified as determined during electrical network studies in the course of conceptual design phase.

Power core conductor design shall comply with IEC 60228 and cross-sectional areas for conductors defined herein. Other conductor profiles shall be agreed in each individual case.

Power core design shall comply with relevant IEC standards, like e.g. IEC 60502 and IEC 60840.

2.3.3.2 Thermal specifications
Current losses from conductors and metallic covers as well as dielectric losses in the insulation are transferred through the cable surface to the environment, e.g. soil, water or air. In steady state conditions, the temperature difference between conductor (limited by the maximum temperature of the insulating material) and ambient depends on the total loss per metre cable and the total thermal resistance. The current-carrying capacity of the cable is largely determined by the thermal properties of its surroundings. A list of cases shall be established and results of an assessment shall be documented. This includes, but is not limited to cable in J- or I-tube, cable buried in the seabed, cable inside conduit or at landfall.

Ambient temperatures, solar radiation or proximity to other cables and pipelines shall be considered, when analysing the current-carrying capacity of cables.

2.3.3.3 Mechanical specifications
The mechanical properties of the cable are strongly influenced by its armour and shall allow all required handling during the manufacturing, storage, load-out, transport, installation, operation phases as well as, if required, repair and decommissioning phases of the project.

Design documentation shall include information about:
— diameter, dry mass and submerged weight
— minimum bending stiffness, axial stiffness and torsional stiffness
— maximum allowable tension (straight pull), maximum allowable tension at bend radii specified by the client/cable manufacturer, e.g. corresponding to the radius of the installation chute, J-tube bend or similar
— minimum allowable bending radius at combined tension and bending, at a tension representative of the touchdown region and any other relevant load case for transport and installation operations
— maximum allowable sidewall pressure at maximum installation tension (relevant for installation over chute) and maximum tension around J-tube bend, if applicable
— maximum allowable twist
— maximum allowable duration of a stand-by condition, alternatively maximum fatigue damage over the cross-section, for specified load combinations (i.e. tension and curvature) provided by the installation contractor
— for coilable designs, minimum coiling diameter, coiling direction and maximum allowable number of coiling cycles
— temperature dependency of properties, where relevant.

Subsea power cables shall be qualified by testing using appropriate mechanical loading which represents
worst handling conditions, if not proven earlier with similar cable design. Testing shall be in accordance with CIGRÉ Technical Brochure 623, see [3.2].

Cable integrity when subjected to applicable crush / squeeze loads (e.g. from stacking, use of cable engine, chinese fingers) and impact from falling objects (e.g. rock placement) shall also be verified by significant testing.

2.3.3.4 Testing specifications
Non-electrical and electrical tests for the cables including the applicable standards shall be specified for verification of design implementation and quality assurance.

2.3.3.5 Power cable accessories
Subsea power cable accessories may include, but not be limited to, the following:

- joints
- termination kits
- cable end caps
- hang-off modules
- pulling head / chinese fingers.

Joints and terminations shall be designed and tested in accordance with applicable IEC standards (e.g. IEC 60502 or IEC 60840) and, if not addressed sufficiently therein, CIGRÉ guidelines, see [3.2].

The design of the termination kit shall be compatible with the selected power cable design, voltage requirements and switchgear design with regard to selected standards, operational requirements, dimensions and materials.

Hang-off or armour terminations of subsea cables shall be designed in accordance with relevant design codes such as DNV-OS-H102 applying the maximum operational and installation loads respectively.

Chinese fingers shall be designed according to recognized lifting standards, e.g. ISO 19901-6 or DNV-OS-H205 considering applicable safety factors. Standard DNV-OS-H206 shall be applied for corresponding qualification and testing.

2.3.3.6 Optical fibres
Subsea power cables may contain a number of optical fibres. The design documentation for the integrated fibre optic cables shall at least include following information:

- fibre type (single-mode or multi-mode) and operational wavelength
- number of fibres, including spare fibres
- dimensions and optical properties of single fibres, e.g. attenuation, bending loss
- construction details
- earthing of metallic parts of fibre optic package
- marking of individual fibres, i.e. colour coding scheme
- testing standard.

It shall be possible to connect the optical fibres of different cables using a standard splicing tool.

Guidance note:
A general expectation for subsea power cables is that continuous lengths of optical fibres are used which do not require splicing in the power cable factory.

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Splices, connectors and splice/connection boxes shall be available for the optical fibres and suitable for the intended application (e.g. offshore).

2.3.3.7 Cables for application in dynamic environment
For subsea power cables connected to floating structures, like e.g. floating wind turbines or wave energy conversion units, aspects shall be considered in addition to [2.3.3.3] for design and mechanical strength in order to reach expected lifetimes. A life-time (fatigue) analysis under consideration of environmental conditions shall be performed.
Dynamic cables shall be designed according to DNV-OS-J301 Sec.16. Dynamic loads generated from waves, currents, wind or motion of the unit shall be pre-determined considering worst-case scenarios and their influence on the cable structure shall be analysed with regard to bending, torsional stress and tensile elongation or a combination of it.

Applied fitting and ancillaries, such as buoyancy and bend stiffeners shall be subjected to a suitability study according to relevant API codes, e.g. API RP 2RD and API RP 2A.

2.3.3.8 Cable route
Information on the detailed cable route [2.2.3.5] shall be available including:

— site constraints (slopes, rough terrain)
— minimum and/or maximum cable segment lengths
— cable constraints (minimum straight segment length between two alter course (A/C) points, on-bottom tension range)
— equipment constraints (minimum on-bottom radius, maximum A/C or arc angle)
— distance from existing cables, related to planned equipment and water depth
— avoidance of (unnecessary) crossings
— preference for straight cable pulls to / from offshore units
— temporary laydown areas, e.g. prior to jointing
— route position list (RPL), acceptable tolerances for the as-laid cable
— requirements for burial depth
— crossing description, if applicable
— landing description, if applicable
— vessel access restrictions, e.g. draught
— areas with rock outcrops / boulders
— areas congested with pockmarks
— distance to UXOs.

When power cables are routed in parallel, the distance between them shall be subject to careful evaluation. Due consideration should be given to a potential repair of the cables and to mutual thermal interference. Laydown space requirements for the repair bight depend on water depth, repair vessel deck height, required deck length and radius of the bight.

2.3.3.9 Crossing of existing infrastructure
Every crossing of existing infrastructure (pipeline, telecommunication cable, power cable) has its own characteristics and shall be assessed separately. Information about the proposed crossing shall be exchanged between the parties concerned as early as possible.

The design of crossings shall be developed and documented based on the considerations given in clause [4.5.4] of DNVGL-RP-360.

2.3.4 Cable protection design

2.3.4.1 General
During installation, cables shall not be subjected to mechanical loads exceeding the cables’ design limits, including tension, bending, torsion and crushing, see [2.3.3.3] and [4.5]. After installation, for the service life of the cable system, cables shall be suitably protected from hazards, such as the following:

— marine (waves, tides) and sediment conditions, e.g. exposure and movement of cable
— unsupported lengths of cable, e.g. in uneven terrain or due to sand waves
— movement of the cable between laying and protection (on-bottom stability), potential for abrasion
— penetration of fishing gear, e.g. during bottom-trawling activities
— dropped or dragged ship anchors, intended or inadvertent
— invasive activities, e.g. dredging
— dropped objects, e.g. lost shipment containers or cargo transferred between vessel and offshore unit
Besides safeguarding from hazards, the design of cable protection along the proposed route shall ensure that relevant limit states and/or cable capacities (e.g. maximum temperature) are not exceeded.

### 2.3.4.2 Burial assessment

A burial assessment study shall provide input to the final cable route design by determining:

- risks along the cable route
- appropriate depth of burial for the cable sections
- suitable (lay and) burial method(s) and resulting trench profiles
- additional protection that may be required.

The cable burial risk assessment methodology (CBRA) may be applied. See DNVGL-RP-360 Sec.4 [4.6.3.2] for further guidance.

### 2.3.4.3 Non-burial cable protection

Where non-burial protection is required the most appropriate technique (or combination of techniques) shall be selected from the range of options available. This refers to:

- the interface between cable and offshore units [2.3.5]
- the immediate vicinity of offshore units where burial is not practical
- infrastructure crossings, e.g. between power cable and pipeline [2.3.3.9]
- boulder, cobble or gravel fields or in very hard (rocky) seabed, including areas with insufficient sediment thickness, where trenching may not be feasible or economic
- areas with mobile sediments
- installation activities (e.g. ploughing) that had been interrupted and where cable was surface laid or minimum burial depth could not be reached
- cable repair (joint) locations.

The design of non-burial protection is driven by the specific application and shall meet the requirements with regard to:

- primary functionality of the cable, e.g. acceptable reduction of current rating
- provision of protection, support and stability
- separation
- flexibility (e.g. with regard to repair or replacement)
- corrosion resistance
- any other risk.

### 2.3.5 Cable interface at fixed offshore units

#### 2.3.5.1 General

The design of the interface between a subsea cable and a fixed offshore unit shall take conditions and limits during installation (primarily mechanical) and after installation (electrical, thermal and mechanical) into account.

Interference of cable pathways with other appurtenances on the offshore structure (e.g. boat access systems, cathodic protection systems) shall be avoided.

Congestion of J- or I-tubes shall be avoided to aid installation and maintain cable temperatures within acceptable limits.

#### 2.3.5.2 Routing and fixing of cables

Low voltage (< 1 kV) power cables should not be bundled together with, run through the same conduits as, or terminated in the same box as cables of high voltage (≥ 1 kV). Cables should be installed well clear of
substantial heat sources unless it is ensured that insulation and current rating are adapted to the actual temperatures and heat accumulation at such locations.

Cables shall be installed so that they are not likely to suffer mechanical damage. Supports or fixing shall be suitably chosen according to the type of cable, expected short-circuit forces and the probability of offshore unit movement and vibration at the point of installation.

Fixing devices should be made of steel adequately protected against corrosion or non-metallic materials with appropriate properties. Braid or armour of lead, bronze or copper should not be installed in contact with aluminium alloy structures.

The minimum bending radius for power cables shall be in accordance with the manufacturers’ recommendations.

2.3.5.3 Cable hang-off
Where cables are secured by hang-off systems, the following shall apply.

The hang-off shall securely anchor the cable by transferring all mechanical loads from the armour to the hang-off structure for the design life of the cable system without compromising the integrity of the cable. The hang-off structure shall be designed according to ISO 19901-6 or DNV-OS-H205.

The stress on the armour wires should remain in a range avoiding premature wear and yielding.

2.3.5.4 Single-core cables
For routing single cores of AC circuits (and for DC installations with high ripple content) at an offshore unit above the hang-off, the following shall apply:

Armour on single-core subsea cables shall be of non-magnetic type.

Single-core cables belonging to the same circuit shall be laid as close as possible and preferably in a triangular (trefoil) formation. They should be contained within the same pipe, conduit or trunk. Clamps that fix them should, if possible, include all phases.

Phases belonging to the same circuit shall not be separated by magnetic material and be run together in a common wall penetration (multi cable transit), unless the penetration system is of non-magnetic material.

2.3.5.5 Cable termination system
All major electrical equipment (transformers, high-voltage switchgears) shall be provided with a suitable, fixed cable termination system in an accessible position with sufficient space for dismantling and connection of external incoming cables.

Optical fibres contained within the power cable should be terminated in suitable boxes / cabinets which provide adequate space for splicing and are designed for offshore use.

Cable entry into the enclosure shall provide effective sealing.

All connections for current-carrying parts and earthing connections shall be fixed so that they cannot loosen by vibration.

Suitable earth connection points shall be provided for fixing bonding leads from cable terminations or cable screen.

2.3.5.6 Interface design
The cable may be routed inside fixed (J- or I-) tubes or through a flexible (J-tube-less) interface. The interface shall be suitably designed to perform the cable transition from a location on / in the seabed to the substructure of the offshore unit. The interface shall:

— allow adequate heat dissipation
— stabilize and protect the cable in the vicinity of the offshore unit’s substructure, taking into account scour, dropped objects, abrasion and vortex induced vibrations (strumming)
— be easily installable.

2.3.5.7 Scour and scour protection
The risk of scour around the foundation of an offshore unit shall be assessed to facilitate proper cable interface design. In an analysis of scour, the sediment properties together with the effects of steady current, waves, or current and waves in combination shall be taken into account as relevant.
A solution to accommodate for scour at the interface between structure and cable shall be found, if the cable is not fitted with an appropriate external protection system that can handle all present static and dynamic loads, spanning the scour hole.

2.3.6 Landfall

2.3.6.1 General
Onshore cabling requires solutions that differ from those for the offshore section. The landscape or site access by land and sea shall be carefully reviewed and planned. Seasonal restrictions, e.g. for environmental reasons need to be considered, if applicable.

2.3.6.2 Onshore jointing location
The land transition jointing location is an important interface between onshore works and coast / offshore works. It shall be designed to:

— provide a safe and stable temporary working area
— have space for winches behind the transition joint bay and for adequate over length of cables to be pulled in
— allow securing the cables mechanically
— allow for the provision of a conditioned environment for jointing activities (e.g. dewatering, air conditioning)
— enable cable commissioning and testing.
SECTION 3 MANUFACTURING AND TESTING

3.1 General
This section describes the minimum requirements for the fabrication and acceptance criteria of subsea cables. The manufacturer shall establish a quality control system which ensures that materials, manufacturing and final testing are in accordance with the standards and codes (e.g. IEC and CIGRE) defined in the design basis. Fabrication of cables, cable components and associated products shall have a documented and implemented quality system conform to ISO 9001. Manufacturing tolerances shall be compatible with design assumptions and internal procedures.

Repair work shall be carried out in accordance with written procedures accepted by the purchaser or his representatives.

3.2 Quality assurance and testing
Manufacturing inspections for quality assurance shall take place based on an established inspection and test plan (ITP) that defines production related quality documentation and success criteria to be applied for each manufacturing step including final tests.

The subsea power cable or its components shall be subjected to a comprehensive test program before, during and after the manufacturing process. This at least shall include the type and routine test for power cable and fibre optics described in DNVGL-RP-360 Sec.5 [5.2].
SECTION 4 TRANSPORT AND INSTALLATION

4.1 General
The installation phase includes offshore and landfall construction activities as well as load-out and transport. Detailed design of the transport and installation steps for the cable system and its interfaces is a process that shall address all possible scenarios such as the following:

- cable storage, load-out and transport
- cable laying, e.g. offshore, in landfall area and/or at infrastructure crossings
- cable pull-in at offshore units and landfall
- cable burial, including burial tools and their characteristics
- cable protection by non-burial methods
- cable jointing
- contingencies.

Predetermined maximum pulling forces required for pull-in operations at structures shall be provided considering:

- friction coefficients of soil and tubes
- cable weight in water and air
- installation tolerances.

Risk assessments, including hazard identification (HAZID), hazard and operability study (HAZOP) and/or failure mode and effect analysis (FMEA) shall be carried out for each step of the installation process. An overall installation manual shall be developed. The installation manual shall include detailed procedures for the individual installation steps, including relevant operational parameters and limiting weather conditions established in the installation analyses.

The chosen installation method shall facilitate control over the cable configuration at all times. The following information shall be included in the installation procedures:

- cable system mechanical properties including submerged weight, tensile strength, minimum bending radius, cable protection devices
- limiting weather conditions for the selected installation spread
- laying parameters (e.g. minimum lay angle, maximum lay tension, minimum layback) to be maintained along the cable route
- detailed cable route engineering (including at offshore units, lay tolerances)
- verification of cable capacity in combined tension and bending and with respect to radial compression from cable engine tracks and chute contact.

Static and dynamic installation analyses shall ensure that the cable’s mechanical properties are adequate for the planned process. The analyses shall provide the control parameters for managing the catenary during the laying process and pull-in, both for typical and worst-case scenarios.

Operational limiting conditions shall be defined based on the intended installation vessel’s or transport vehicle’s capabilities, the planned installation techniques, the applicable weather windows and contingencies.

Continuous monitoring and recording of the measuring devices required for control of the operational limiting conditions shall be performed during all phases of installation activities.

The operational criteria shall account for uncertainties in both, weather forecasts and monitoring of environmental conditions. Regular weather forecasts from a meteorological centre shall be available on-board the cable installation vessel, supplemented by historical environmental data.

An operation shall be planned in such a manner that the product can be brought into a safe condition. If the planned duration of an operation including contingencies exceeds 72 hours, procedures should be developed to establish a safe condition in the event that the weather forecast should indicate that the limiting weather conditions for the operation may be exceeded prior to completion.
A safe condition is defined as a condition in which weather conditions in excess of the limiting weather conditions for an operation will not jeopardise the required level of safety for the product and its integrity. A safe condition may be established by:

- completing the operation,
- reversing the operation,
- abandoning the operation, or
- a stand-by configuration that ensures that product integrity is maintained until normal operations can be resumed.

Time needed to establish the safe condition should be considered, as well as the safety of personnel working on deck under the specified limiting weather conditions. Further guidance related to general planning of operations may be found in DNV-OS-H101.

Limiting weather conditions for an operation shall be specified considering cable capacities, limitations to installation equipment, personnel safety, previous experience and other relevant factors as applicable.

The maximum allowable duration of a stand-by configuration should be specified along with applicable operational parameters to ensure that relevant limit state criteria are not exceeded. Environmental data for the calendar month of the operation, as well as the succeeding month should be considered. If an operation is to be carried out within the first 10 days of a month, environmental data for the preceding month should be considered. In this case, however, data for the succeeding month may be omitted.

**Guidance note:**
Additional requirements may be imposed by the appointed Marine Warranty Surveyor (MWS) on the basis of established guidelines and recommendations.

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### 4.2 Cable storage

After completion of the manufacturers’ testing program on delivery lengths, the cable shall be suitably stored until load-out is undertaken.

Adequate space shall be available at the construction site considering planned landfall and offshore installation schedules. Storage space should be considered to accommodate for changes in installation schedules.

Storage conditions shall be defined and confirmed by the cable manufacturer, considering the potential for damage, based on the risk assessment performed.

The following should be considered as a minimum:

- limits of mechanical forces, acceptable stacking heights
- limits of exposure to solar (UV) radiation, temperature, humidity
- suitable protection of cable ends (sealed in accordance with manufacturer’s recommendations)
- maximum time allowed for chosen storage solution
- maximum no. of and conditions for coiling/winding/rewinding processes over lifetime.

The following shall be documented for storage facilities:

- adequate foundation (ground conditions and structural support) for the weight of the cables
- adequate protection from environmental influences
- adequate drainage of water
- measures to prevent icing.

Access to cable ends (including optical fibres) for testing purposes shall be considered.

### 4.3 Cable load-out

Load-out limiting conditions shall be defined, considering the potential for damage of the cable.

A load-out procedure for the cable (and, if applicable, the cable protection system) shall be developed,
considering all interfaces such as onshore / quayside conditions and transport / installation vessel conditions (or in case of land transport conditions of e.g. the vehicle).

The procedure shall also include handling and sea fastening of ancillary components such as joints and terminations. Communication procedures and the responsibilities at each moment of the load-out procedure shall be clearly defined, including control and monitoring of loading operations and the agreed point of handover from manufacturer to installer / purchaser.

A detailed loading plan shall be produced well in advance of the loading campaign. Loading trials should confirm the suitability of the loading setup prior to loading of the actual cable.

Cable tests prior to load-out shall be carried out as an integrity check, if the cable has been stored for a period longer than 3 month (ISO 13628-5, Sec.14 [14.5]).

Tests / Inspections of power cables prior to load-out (revealing major damage) shall include a selection of:

- general visual inspection - serving or armour damages
- electrical conductors / insulation (all cores) - DC resistance test, insulation resistance test, VLF test and/or time domain reflectometer (TDR) test
- sheath test - DC resistance on single-core sheath, if not semi-conductive
- optical fibres (if present, selected fibres) - optical time domain reflectometer (OTDR) trace, one end.

Transfer and lifting of the cable shall be conducted safely to avoid damage to equipment and product or harm to personnel. The equipment used for transfer and lifting shall not impose damage to the cable. All mechanical loads imposed on the cable shall be less than the limits specified for the product.

4.4 Cable transport

During transport, the properties of power cables should be protected through suitable and careful loading. Cable drums / reels or carousels shall be secured properly.

Sea fastening shall be in accordance with stipulations defined in DNV-OS-H206.

4.5 Cable installation

A cable length identification system shall be used to maintain records of cable / drum numbers, cable lengths, cumulative length, field joints and repair numbers.

The lay configuration and loads shall be controlled in order to ensure that these are within the design envelope during installation (Figure 4-1). The configuration and loads may be controlled by various means. These shall be clearly described, including allowable ranges for the specific sections of the installation.

The cable tensioner’s shall have suitable holding capacity to prevent product slippage during installation. As the tensioner squeeze force depends on various factors, e.g. contact length with the cable, friction coefficients of tensioner pads and cable or the cables squeeze force limits, the minimum squeeze force shall be calculated or analysed avoiding too fast lowering of the cable.

![Figure 4-1 Cable laying process](image-url)
The cable lay process shall be monitored and controlled. Parameters monitored may include water depth, top tension, departure angle, lay back distance and touch-down point as well as environmental parameters and vessel motion. Depending on the installation vessel and cable, the preferred methods may change.

The cable shall be laid within an acceptable range of top and bottom tensions and without violating the cable minimum bending radius or maximum allowable cable squeeze loads.

Cable lay operations shall be carried out using positioning systems with the accuracy (see [4.5.4.2]) necessary to meet the installation conditions assumed and requirements defined in the design phase. Measures shall be taken to avoid damage to existing infrastructure, specifically in congested areas, in the vicinity of existing installations and at pipeline and cable crossings.

The cable end storage procedure shall be defined and accepted before start of cable laying operations. Requirements with regard to sealing against water ingress and protection against the risk of cable damage shall be applied and implemented. The end caps shall be mounted in accordance with the cable manufacturer’s specifications.

The position of the cable shall be verified to be within its target area prior to departure of the lay vessel from site, see [4.7].

4.5.1 Jointing

Jointing activities require:

— detailed planning of the entire process
— (repair) joint kit
— qualified and well-trained crew
— for offshore joints, a suitable vessel and equipment (stability, length for cable laydown, handling of two cable ends, etc.)
— for offshore joints, an adequate window of safe weather conditions
— controlled environment with temperature and humidity within ranges specified by the manufacturer.

Guidance note:
For guidance on joints, see CIGRÉ Technical Brochures 177 and 490. For guidance on cable accessory workmanship, see CIGRÉ Technical Brochure 476. Guidance on qualification of transition joints is given in CIGRÉ Technical Brochure 415. General information on joints are given in TB 610.

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4.5.2 Cable pull–in to offshore unit

Project specific pull-in procedures shall be developed. The procedure shall be based on pull-in analysis considering friction due to contact with guide tubes and seabed, as appropriate, and effects of vessel motion (e.g. by incorporating a dynamic amplification factor).

Monitoring of the pull-in and cable tension shall be provided throughout the pull-in operation.

4.5.3 Landfall

4.5.3.1 General

Landfall activities include equipment mobilisation, landfall preparation, positioning of cable installation vessel, cable pull-in, cable burial and demobilisation.

Risks to persons and the environment shall be considered, as well as the presence of third parties (e.g. recreation). Appropriate security measures and communication shall be established. In accordance with regulations, the construction area shall be clearly marked with warning signs and fenced off as appropriate to assure safety of the public.

The site layout, transport of equipment to the site and landfall preparation works (open-cut trench installation, horizontal directional drilling) shall be executed in accordance with the criteria and assumptions specified in the design phase.
4.5.3.2  Cable pull-in
Detailed requirements for the execution, inspection and equipment testing of the shore pull shall be specified and documented, considering the nature of the particular installation site.

Pulling heads and other equipment shall be dimensioned for the anticipated forces (not exceeding the mechanical specifications of the cable) and provide a secure connection. Please see [2.3.3.5].

Monitoring and measuring devices shall be used during execution of the shore pull. Continuous monitoring of the applied cable tension and pulling force shall be performed to ensure that they are within allowable limits of the cable.

The winches shall be equipped with sufficient line and indicators / recorders for line tension and length paid out. All measuring equipment shall be calibrated, and an adequate amount of spares to ensure uninterrupted operation should be provided. Prior to actual cable pull, the winch unit’s pulling force should be verified through testing. It shall be ensured that its specified static line pull (rated max. static pull tension of winch) exceeds the maximum pull-in load.

4.5.3.3  Interface with land-based system
The land – sea transition joint bay area, see [4.5.1], shall be constructed in accordance with the design documentation. Depending on its location, temporary measures for dewatering may be required.

The jointing of subsea and land-based cables at the land – sea transition joint bay shall be carried out in accordance with the procedure developed for the particular cables and approved by the cables’ manufacturer.

4.5.4  Cable protection

4.5.4.1  General
The requirements of this subsection are applicable to the protection of cables, e.g. direct burial including trenching and backfilling, and other methods such as gravel and/or rock placement, grout bags, concrete mattresses, etc. It is also applicable to free span rectification.

4.5.4.2  Cable burial
Prior to burial operations it shall be confirmed that the trenching method considering the given cable submerged weight, soil properties and near-bed hydrodynamic conditions will ensure that target burial depth is met.

The trenching equipment shall be designed so that it does not place significant loads on the cable and that it minimises the possibility of cable damage.

The burial operation shall be suitably monitored. The burial equipment monitoring system shall be calibrated and include at least:

— devices to measure trenching and cable depth relative to seabed level
— a control system preventing horizontal loads on the cable
— devices monitoring pitch, roll, depth, and the absolute underwater position of the burial equipment.

A post-burial survey shall be performed in order to determine if the required depth of lowering and depth of cover have been achieved and if any remedial work is required, see [4.7].

4.5.4.3  Non-burial protection
Placing of cable protection materials shall be performed in a controlled manner. Scour protection layer formation techniques (e.g. rock dumping method) at offshore structures shall not lead to any damage of the cable or cable protection system when having the subsea cable installed already. Restrictions on vessel movements and weather limiting conditions during the operation shall be considered, too.

During the placement operations, inspections shall be performed, e.g. with an ROV-mounted video camera, to determine the completeness and adequacy of the installation.

Existing infrastructure shall not be disturbed or interfered with.
4.6 Infrastructure crossings
Preparations for crossing of pipelines and cables shall be carried out according to a specification detailing
the measures adopted to avoid damage to both installations as written in the crossing agreement.

The operations shall be monitored visually to confirm correct placement and configuration of the supports.
Support and profile over the existing installation shall be in accordance with the accepted design.

Special precautions shall be taken when transferring the cable burial equipment from one side of the
existing infrastructure to the other.

4.7 As-built survey

4.7.1 General
An as-built survey covering the complete subsea cable system shall be performed to verify that the
completed installation work meets the specified requirements, and to document any deviations from the
original design.

The as-built survey shall be performed after work on the subsea cable system and its end points, including
all applicable working steps like, e.g., laying and burial, crossings, rock placement, artificial backfill, etc.
are completed.

4.7.2 Survey requirements
The as-built survey data shall include, but is not limited to the following information:

— horizontal and vertical position of the cables, also with regard to permitted tolerances of the cable route
— depth of lowering and/or depth of cover, as applicable, if not ascertained during burial operations
— identification and quantification of any free spans with length and gap height
— location of damage to cable (if applicable)
— evidence that the condition of cable protection is in accordance with the design specification.

The data shall be reviewed and non-conformities identified and clearly documented.

4.8 Termination
The termination location may be within an area which requires confined space entry for which the necessary
safety precautions shall be taken.

The armour wire termination shall be electrically earthed at the designed earthing point, using an
appropriate earthing kit.

High voltage cables shall be fitted with qualified ending or termination kits. These shall be suitable for the
intended termination point and application. The termination kit shall be manufactured and tested for the
specified voltage level (see [2.3.3.5]).

Cable termination systems shall be installed according to the manufacturers’ installation manual by using
prescribed tools. The technician shall be qualified and trained on the type of termination kit to be installed
and in possession of the related certificate.

The optical fibres shall be connected in a splice box in accordance with the design documentation.

Guidance note:
For guidance on cable accessory workmanship, see CIGRÉ Technical Brochure 476. For guidance on maintaining the integrity of XLPE
cable accessories, see CIGRÉ Technical Brochure 560. General information on joints are given in TB 610.

Due to the combined electrical testing of HV AC termination kit components, only these approved parts shall
be installed together.
SECTION 5 COMMISSIONING

5.1 General
Subsea cables and fibre optic elements shall subsequently be commissioned after successful laying and installation. Fixation, testing and termination works shall be carried out before the cables will be put into operation.

5.2 Testing after installation
After installation and before a cable system is ready for operation or put into service, it shall be visually inspected and electrically tested according to CIGRÉ TB 490 for AC, TB 496 for DC or the relevant IEC standard. Inspection and testing activities shall at least include the following:

— check of routing and fixing in offshore units and termination (mechanical, electrical) of the cable in accordance with the design documentation.
— optical time domain reflectometer (OTDR) measurement, provided that the power cable contains optical fibres or is bundled with a fibre optic cable.
— high voltage test of cable system (including termination).
SECTION 6  IN-SERVICE

6.1  General
This section provides requirements for the safe and reliable operation of a subsea power cable system during its life-time with the main focus on management of cable integrity. The cable owner / operator shall establish and maintain an asset management system for subsea cable installations which complies with regulatory requirements, when not included in an overall offshore wind farm management system.

6.2  Operation planning
The cable system shall be operated in accordance with the design and operating premises. Adequate performance shall be assured with regard to health and safety, the environment and required system availability.

The following shall be taken into account:

— philosophy for maintaining the integrity of the cable system
— design and function of cable system
— operational conditions of the cable system
— probability and consequence of failures
— monitoring, testing and inspection methods
— spare part considerations (policy, inventory).

Detailed procedures for in-service activities shall be established prior to start-up of operation. Design and operating premises and requirements shall be provided prior to start of operation and updated during the service life. These premises and requirements may be, for instance, linked to the following:

— voltage, current, power, temperature (overloading, insulation deterioration)
— cover of buried cable sections (inadequate or excessive cover)
— free spans length and height (associated stress).

6.3  Maintenance and monitoring requirements
Objectives for (continuous) monitoring are to record the status of the cable system, to detect changes in operating conditions and to take mitigation actions such as restricting operational parameters (e.g. electrical current, temperature). Conditions of the cable which are monitored may include:

— electrical - voltage, current, power
— thermal - temperature
— mechanical - tension, bending, vibration.

Where testing activities are specified to be carried out during the operational phase, the activities shall be planned, executed, reviewed and documented. CIGRÉ Technical Brochure 610 shall be applied for such purpose.

A detailed external inspection plan including specifications for the inspections shall be prepared for each survey. The detailed inspection plan should be updated based on previous inspections as required.

External inspection shall be carried out to ensure that the design requirements remain fulfilled and that no damage has occurred. The inspection programme shall, as a minimum, contain following inspection under water:

— exposure and burial depth of buried or covered cables
— free spans including mapping of length, height and end-support conditions
— condition of artificial supports installed to reduce free span
— local seabed scour, settlement, subsidence or instability affecting the cable integrity
— mega ripple / sand wave movements affecting the cable integrity
— cable settlement in case of exposed sections
— the integrity of cable protection covers (e.g. mattresses, covers, sand bags, gravel slopes, etc.)
— mechanical damage to cable
— major debris on, or close to, the cable that may cause damage to the cable.

The sections at the offshore units shall be part of the long-term external inspection programme for the cable system including:

— functionality of supports and guides and integrity issues (e.g. cracks in welds)
— damage or displacement, e.g. due to vessel impact or foundation settlement
— corrosion, e.g. of J- or I-tubes
— damage to coating
— extent of marine growth.

The frequency of future external inspections shall be determined based upon an assessment of:

— authority and cable operator requirements
— degradation mechanisms and failure modes
— probability and consequences of failure
— seabed dynamics, e.g. mega ripples or sand waves
— results from previous inspections
— changes in the operational parameters
— requalification activity and results
— repair and modifications
— subsequent cable laying operation in the area.

Critical sections of the cable system vulnerable to damage or subject to major changes in the seabed conditions should be inspected at suitable intervals.

6.4 Repair work

6.4.1 General

All repairs shall be carried out by qualified personnel in accordance with agreed specifications and procedures defined for the cable. CIGRÉ TB 610 shall be applied.

Spare cable, repair parts and material such as jointing kits shall be stored suitably protected to prevent deterioration or damage. Where applicable, expiration dates should be clearly marked on the parts and material.

In specific circumstances, longer term storage of spare cable on or in the seabed (wet storage) may be allowable after agreement.

6.4.2 Repair planning and execution

Operational limiting conditions with regard to the sea-state, current and vessel movements shall be established. The level of uncertainty in weather forecast shall be taken into account. Detailed procedures shall be established based on analyses, see Sec.4. The position of the repair shall be verified prior to start of operations. A survey shall be performed to establish that the location is free of obstructions and that the seabed conditions will permit the repair to be performed as specified.

Potential anchoring requirements and the laydown of the repaired cable shall be carefully planned.

A repair joint shall be laid in line with the cable (or within straight leg of a cable repair bight), preferably not within an arc. Arrangements and equipment for lifting and lowering of the repair bight shall be analysed to determine the critical parameters and limiting criteria for the operation. Critical parameters / limiting criteria shall be monitored continuously.

Mounting operation of joints shall be performed in accordance with the manufacturer’s procedure. During
all handling, lifting and lowering into the final position, the cable and the joint shall be protected against mechanical damage (tension, bending, etc.). Bend stiffeners and/or bend restrictors used at either side of the cable joint shall be approved by the cable manufacturer.

All repairs shall be inspected and electrically tested by experienced and qualified personnel in accordance with agreed procedures. Testing personnel, equipment, methods, and acceptance criteria shall be agreed upon in all intervention and repair works shall be documented.
SECTION 7 DECOMMISSIONING

7.1 General
Decommissioning is the set of activities associated with taking the cable out of service. Depending on applicable legislation, out-of-service cables may be abandoned (requiring future management) or removed. Cable decommissioning shall be planned and prepared.

Where a future use of the a cable is anticipated, decommissioning should be planned, conducted and documented in such a way that degradation mechanisms are reduced and the cable can be re-commissioned and put into service again.

7.2 Removal process
The decommissioning concept, including the withdrawal from service and abandonment / removal options, shall cover the following:

— relevant national and international regulations
— natural environment (benefits of not disturbing the seabed, possible pollution, future effects)
— obstruction for surface navigation, also in comparison to existing installations, wrecks and debris
— mobility of sediments and change of the cable presenting a hazard over time
— future management of an out-of-service cable system
— procedure and technical feasibility of cable removal.

Sections or complete out-of-service cables that are planned to be removed should be classified by their destination, i.e. scrap or re-use. This classification will to some extent define the failure modes, limit states and acceptance criteria which shall be checked.
APPENDIX A DOCUMENTATION

A.1 General
A comprehensive set of documentation shall be provided issued by different stakeholders, as a whole describing the overall life cycle of a subsea power cable. The following listing defines the minimum of documentation required.

A.2 Preliminary design
An overall design philosophy including general approach, principles, layouts and definitions shall be established for the cable project. The following documentation shall be developed in the preliminary design phase:

— summary report and detailed analysis results including recommendations and supported by relevant maps, figures and tables.
— data presentations in the form of charts, including the proposed cable route together with pertinent features
— analysis of project area / route, geology, terrestrial and marine conditions, environmental impact, third party activities, regulatory requirements
— preliminary route assessment and route recommendations
— preliminary recommendations for cable protection design.

A design basis shall be developed that includes the following, as a minimum:

General:
— cable system overview including general arrangements, boundary conditions and key operational parameters
— reference to detailed project description and functional requirements
— hierarchy of applicable codes, standards and regulations
— general design approach, methods to be used
— HAZID/HAZOP.

Technical interfaces:
— coordinates of interface points, principal cable routing and lengths
— description / drawings of offshore units and landfall area
— mechanical interface conditions (e.g. cable joint or switchgear)
— electrical interface conditions
— optical interface conditions.

Manufacturing and storage aspects:
— manufacturability conditions
— material properties and quality, as applicable
— cable sizing and handling data
— testing requirements.

A.3 Detailed design
The readiness for manufacturing shall be proven after refinement of the design. The following documentation shall be developed as part of detailed design phase therefore:

— systematic review of hazards, risk register, contingency measures
— materials selection
— electrical and thermal calculations
— design reports of cable, joints, terminations and other ancillaries, if relevant
— cable route design [2.3.3.8]
— cable end point interface design
— cable installation analysis addressing critical operational steps identified in the HAZID/FMECA
— procedures for storage, load-out, transport, installation, commissioning, operation, maintenance, repair and decommissioning.
— GIS information and drawings provided for the manufacturing of components or installation of the cable system should include, but not be limited to:
— cable route drawings including seabed topology, existing infrastructure, etc.
— alignment sheets
— drawings and design reports, if applicable, of infrastructure crossings
— offshore unit layout with cable path and details of interfaces
— cable protection design report (burial, non-burial protection)
— non-burial cable protection specifications, material information, design calculations.

A.4 Manufacturing and testing
Manufacturing processes and quality assurance measures shall be described by following documentation.
— quality plan
— manufacturer’s quality system manual
— manufacturing procedure including test requirements and acceptance criteria
— electrical / thermal / mechanical calculations demonstrating the suitability of the component
— component specifications and drawings.

A.5 Transport and installation
An installation manual shall be available, which is defined as a document or collection of documents required for performing the project specific installation work including normal and contingency operations and acceptance criteria.

The installation manual shall be prepared in order to demonstrate that methods and equipment used by the installation contractor will meet specified requirements and that the results can be verified. The installation manual shall include detailed procedures for normal and contingency operations, and shall address all installation steps, including examinations and check points. The manual shall reflect the results of the risk management studies performed for the installation and shall state requirements for the parameters to be controlled (e.g. max/min allowable lay angle, lay-back etc.) and the allowable range of parameter variation during the installation.

The installation manual shall contain the following information as a minimum:
General:
— risk management plan
— hazard identification (HAZID) studies, hazard and operability (HAZOP) studies, failure mode and effect analyses (FMEA)
— simultaneous operations procedures
— diver intervention procedures, if applicable
— contingency procedures (e.g. failure of positioning system)
— plan of in-process inspections and post-installation tests
— qualification and competence requirements for personnel.
— alignment sheets
— procedures related to route preparations, including pre-lay grapnel run
— cable load-out procedures
— cable transport procedures
— cable trans-spooling procedures, if applicable.
— cable laying and catenary management
— cable pull-in preparation and cable pull-in procedures
— cable protection and burial procedures
— cable crossing, if applicable
— abandonment and recovery (A&R), wet storage
— cable jointing procedures, if applicable
— cable repair procedures.

Landfall:
— landfall site preparation procedures
— burial procedures
— cable pull-in preparation and cable pull-in procedures.

Marine logistics:
— vessel mobilisation
— procedures for set-up of navigation and positioning systems, including dynamic positioning trials
— operational limiting conditions.

The as-built documentation to be submitted after installation and commissioning:
— as laid drawings
— daily reports including forecasted weather
— installation and commissioning test reports
— updated GIS information and drawings.

A.6 Commissioning
Cable commissioning of subsea cables refers mainly to termination works. The following shall be provided:
— cable termination commissioning procedures
— cable system testing procedures.

A.7 In-service
The cable asset has to be maintained and inspected during the operational phase in order to secure investments and reach assumed lifetimes. The following procedures shall be available.
— repair strategy and procedure
— inspection, testing and maintenance procedures.

A.8 Decommissioning
A decommissioning concept shall be provided laying down the principles and boundary conditions for future removal works after the cable asset will have been put out of operation.
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