Technical Standard for

Subsea Power Cables

ABS

March 2026

TECHNICAL STANDARD FOR

SUBSEA POWER CABLES
MARCH 2026

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

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Foreword

The *Technical Standard for Subsea Power Cables* applies to the design, fabrication, transportation, installation, commissioning, testing, operation, and maintenance of subsea power cables. It also covers independent third-party (I3P) design reviews and inspections to be carried out by ABS during those stages.

This document may be used in conjunction with applicable ABS Rules and Guides, recognized codes, standards, and international regulations.

The effective date of this document is the first day of the month on which it is published. Users are encouraged to periodically visit the ABS website at www.eagle.org to confirm they are referencing the most up to date version of the document.

ABS values your input. Any feedback, comments, or suggestions can be submitted electronically by email to **rsd@eagle.org**.

TECHNICAL STANDARD FOR

SUBSEA POWER CABLES

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SECTION 1
General

1 Introduction

Subsea power cables are vital infrastructure for transmitting electrical power over long distances underwater, serving as key links between offshore units and onshore grids, and multiple offshore installations. These cables are used in a wide range of applications, including offshore wind farms, renewable energy systems (wave, tidal, solar PV), fixed and floating offshore units, interconnectors, and subsea power transmission networks.

The design, installation, and operation of subsea power cables pose unique challenges due to the harsh marine environment, significant water depths, and extended cable lengths. These factors necessitate rigorous standards to achieve the safety, reliability, and longevity of the cable systems.

This document outlines technical requirements for subsea power cables, providing guidance to engineers, project managers, and other stakeholders throughout the entire lifecycle of these key assets.

The requirements specified in this document address key aspects of subsea power cable projects, including design, fabrication, transportation, installation, commissioning, testing, operation and maintenance. The intent of this standard is to assist the industry to mitigate risks, maintain system integrity, and enhance the overall resilience of subsea power transmission systems.

This standard is intended as the minimum technical requirements for subsea power cable systems used in offshore applications across various project phases (design, fabrication, transportation, installation, commissioning, testing, operation, and maintenance). It also outlines minimum independent third-party (I3P) design review and inspection requirements for subsea power cable systems. As outlined in the ABS Guidance Notes on Independent Third-Party(I3P) services, ABS can offer I3P services for individual components and/ or project or specific project phases.

3 Scope and applicability

This document applies to subsea power cables installed in offshore environments, and provides the following:

i) Technical requirements: Specifies the minimum technical requirements for the design, fabrication, transportation, installation, commissioning, testing, operation, and maintenance of subsea power cable system and related projects.

ii) Independent third-party (I3P) design evaluation: Defines the minimum I3P design review services for subsea power cable systems and related projects.

iii) Independent third-party (I3P) inspection: Defines the minimum I3P inspection services for the fabrication, transportation, installation, commissioning, testing, operation and maintenance of subsea power cable systems and related projects.

The requirements in this document are intended for subsea power cables with:

i) Nominal voltages: up to and including 500kV AC, 600kV DC for static cables. Up to and including 132kV for dynamic cables.

ii) Conductor material: Copper or Aluminum.

iii) Number of cable core: Single core and three core AC cable. Single and bundle two core DC cable.

iv) Insulation material: Extruded insulation (XLPE, EPR), mass-impregnated paper (DC cable), equivalent or better.

v) Subsea power cable composition: with or without integrated optical fiber cables.

vi) Cable type: Refer to Table 1 below for applicable cable types.

Table 1
Overview of Various Cable Categories

Category	*Subcategory*	*Description*	*Key Features*
Application	Export Cables	Transmit power from offshore facilities to onshore substations.	AC or DC, with robust armoring and high-grade insulation.
	Array/Inter-array Cables	Connect offshore units (e.g., turbines) within a facility to a central offshore substation.	MV/HV, flexible design
	Interconnect Cables	Link two separate electrical grids or facilities.	long-distance transmission capability.
Voltage Level	Medium Voltage (MV)*	Rated 1–36 kV.	XLPE/EPR insulation, suitable for moderate distances.
	High Voltage (HV)*	Rated 36-230 kV.	Typically, AC or DC.
	Extra High Voltage (EHV)*	> 230 kV	Advanced insulation materials. AC or DC
Insulation Type	XLPE, EPR	Common insulation materials with excellent electrical and thermal properties.	Heat-resistant, lightweight.
	Mass-Impregnated (MI)	Used in HVDC systems.	Low maintenance.
Transmission Type	AC Cables	Used for short-to-medium distances; common in array and export cables.	Requires reactive power compensation for long distances.
	DC Cables	Efficient for long-distance, high-capacity transmission.	Low loss, high capacity
Operational Environment	Static Cables	Fixed or seabed laid installations	High tensile and compressive strength; protective armoring.
	Dynamic Cables	Designed for floating or moving structures.	Flexible, fatigue-resistant; may include bend stiffeners or restrictors.

Note:
The voltage ranges of MV, HV and EHV may differ in different standards or countries.

5 Application

This document applies to interconnectors and subsea power cable systems associated with offshore wind farms, offshore renewable energy sources (including wave, tidal, and solar PV), and other offshore assets. Unless otherwise specified, the subsea power cables addressed in this document include AC and DC cables rated up to 500kV for AC and 600kV for DC. Onshore cables are excluded from the scope of this document. The boundary between the subsea power cable and the onshore cable is defined at the shore-side sea/transition joint, including the sea/transition joint, see 1/11 for location of sea/transition joint, which serves as the boundary limit for this document.

7 Compliance

Users of this document are to be aware that, due to evolving regulations and the specific type of subsea power cable system project, compliance with this document may not address all requirements at the time of fabrication or during subsequent installations. Adhering to the applicable edition of this document, along with other relevant industry technical standards in effect at the time the service is provided, may not fully reflect updates to industry standards that could apply during installation.

This technical standard contains a mix of requirements and procedures. The expectations of stakeholders when applying this standard are as follows:

i) Requirements are indicated throughout the document using the phrases "is to" or "are to". Requirements are to be complied with in order for ABS to issue an I3P certificate. When a requirement does not reference a technical standard or a clear prescriptive requirement directive, a company standard may be applied.

ii) This document covers procedures that should be followed in each phase: Design, Fabrication, Installation, Commissioning and Testing, and Operation and Maintenance. To issue I3P Certification covering the full scope of a specific phase, the procedures are to be followed. Documentation demonstrating that these procedures have been followed is identified in Section 2 (plans and data to be submitted). ABS will review the procedures for completeness.

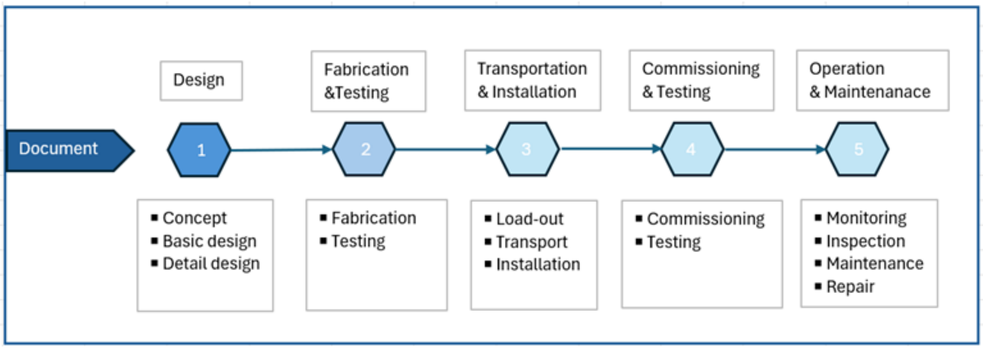
iii) For electrical testing requirements, IEC standards have priority.

For ABS I3P service applications using this document, in the event of any conflict between different technical standards, the following order of precedence is to apply ABS standards, IEC, CIGRE, and API.

9 Project phase

This document will cover the project phase of subsea power cables, including design, fabrication and testing, transportation and installation, commissioning & testing, operation & maintenance shown on Figure 1.

Figure 1
Project Phase



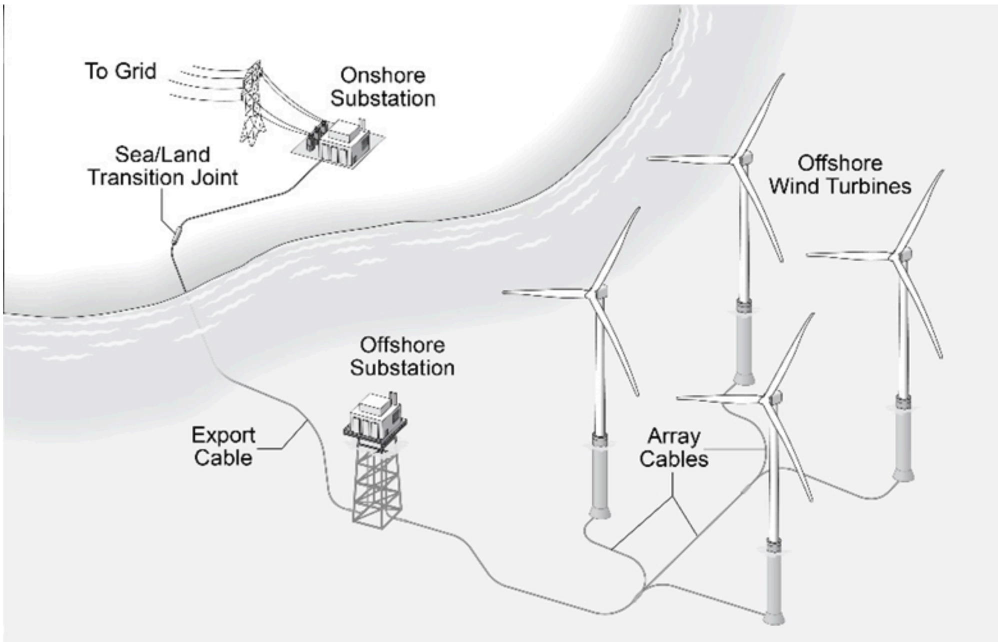
11 Terminology for offshore wind farm

Array cable. Array Cable (shown in Figure 2) in offshore wind project is used to connect individual wind turbines to each other and to transmit the power produced by several wind turbines to the offshore substation.

Export cable. Export Cable (shown in Figure 2) in an offshore wind project connects the offshore substation to the onshore power grid. The boundary between the export cable and the onshore cable is defined at the shore-side sea/transition joint. This joint is included within the scope of ABS review.

Wind farm. Energy production facilities, including all their main components, that are used to produce electricity and deliver it to the grid. A wind farm (as shown in Figure 2) is associated with the main installation wind turbines and substations including their support structures and power cables.

Figure 2
Offshore Wind Farm



13 Definition

The following terms are used in this document:

Anchoring devices: Devices used to secure subsea cables to prevent unintended movement due to gravitational forces at steep landfalls or seabed shifts or underwater currents. Like hang-offs, anchoring devices are intended to firmly fix the shore end of the subsea cable to the ground. They are typically mounted on a steel structure supported by a concrete foundation for added stability.

Ambient temperature: For test conditions, unless otherwise specified in the details for the test, tests are to be carried out at an ambient temperature (20±15)°C.

After installation test: Tests made to demonstrate the integrity of the cable system as installed.

Ancillary: Supplementary components, devices or systems that support the installation, operation, protection, and maintenance of subsea umbilical and power cables. They are attached to flexible pipes or umbilical that serves multiple functions. These include controlling the pipe's behavior, providing a structural transition, enabling attachment to other structures, protecting or repairing the pipe, and creating a seal along its length. Ancillary as per umbilical & API 17L1 includes buoys, bend restrictors, and other similar components.

Accessories: Components or devices that are used in conjunction with subsea power cables to support their proper installation, operation, protection, and maintenance. Key accessories, referred to as “electrical accessories” in IEC standards for subsea power cables, include joints, terminations, and connectors.

Ballast modules: Ballast modules are used to balance upward and downward forces, helping to stabilize dynamic cable configuration and minimize the formation of compressive waves.

Bell mouth: Interface at the cable to platform junction. The bell mouth protects the cable from overbending at the point where the cable exits the guide tube at an angle.

Branching joints: A joint is used to connect multiple cables, such as splitting power to multiple loads or connecting additional circuits.

Bending stiffeners: A stiffener is used to gradually increase cable bend stiffness where the cable is connected to the platform or other rigid structure.

Buoyancy attachments: A device used to relieve topside tension as well as decouple the touch-down point from heavy motion of the moving platform.

Cable system: A cable system includes cables and various installed accessories and ancillaries, typically joints and terminations. Other accessories, such as measuring devices or fixtures, may also be part of the system. These additional components only need to be included in test objects if they are expected to influence the cable system's operational performance.

Cable protection: In areas subject to higher external mechanical impacts or in crossing zones, additional protection may be required. This can be achieved using cast-iron half shells, polymeric enclosures, or other protective measures to safeguard the cable.

Cable grips: A gripping device used to hold cables by their outer diameter, consisting of spirally interwoven wires or synthetic rope connected to an integrated anchorage arrangement. Cable grips are used for pulling in or suspending cables during installation.

Condition based maintenance (CBM). To perform preventive maintenance based on the current condition of the component through condition assessment.

Certification: The formal process of verifying that a person, product, or organization meets specific standards, requirements or qualifications set by a recognized authority or governing body. In this document, if the term “certification” falls under the scope of ABS, it will be labeled with I3P.

Critical points: Critical points for the installation of bend restrictors or stiffeners at specific locations where cables or subsea cables are most susceptible to over-bending or mechanical damage due to external forces, installation conditions, or operational stresses. These points are vital because excessive bending can lead to cable fatigue, structural damage, or operational failure.

Delivery length: A delivery length refers to the intended shipping length of the subsea cable and may consist of one or more manufactured sections joined with factory joints. Typically, on a drum, in a coil or on a turntable.

Development tests: A series of tests conducted on new cables or accessories to evaluate and validate their designs, materials, components, production processes, installation conditions, or long-term performance. The scope and specifics of these tests are determined by the fabricator. Following these development tests, the cables and accessories undergo standard type and/or pre-qualification testing programs.

Dry design: In dry design cables, a metallic water barrier (typically, an extruded lead or aluminum or copper sheath) inside the cable power core but above the insulation and associated screens, which is intended to keep the insulation system dry for the lifetime of the cable.

Dynamic loads: Load resulting from wave-induced motions, ocean currents, tidal fluctuations, wave action, vortex-induced vibrations (VIV), movements of offshore assets (e.g., floating platforms or vessels), and forces encountered during installation and handling operations.

Dynamic cable: A cable designed to withstand dynamic loads throughout its operational life, with these loads arising directly or indirectly from wind, waves, and currents. Typically, a dynamic cable extends from a host facility to the seabed, accommodating constant movement and environmental forces.

Dynamic tether clamp: to hold the dynamic system in place, preventing lateral and axial motion of the dynamic system. *Design life:* the duration for which a product (component, equipment, system, project) is expected to perform its intended function with routine maintenance, but without substantial major repairs.

Extension of prequalification (EQ) test: Tests conducted prior to the general commercial supply of a specific type of cable system as outlined in this document. These tests aim to demonstrate the satisfactory long-term performance of the entire cable system, considering an already pre-qualified cable system.

External design of joint: This refers to the design focused on the mechanical functionality of the joint. It is engineered to withstand impacts from the surrounding environment, as well as mechanical bending, tension, and torsion during installation and operation. The joint can be either rigid or flexible and may be designed for single-core or three-core configurations.

Environmental conditions: Environmental conditions refer to the internal, external, and operational factors that the system is exposed to. These include physical, chemical, biological, and usage-related factors, such as seawater environment, water depth, seabed conditions, temperature, marine growth, and other relevant conditions.

Factory joint: A factory joint is an in-house connection between manufactured cable lengths, used when the delivery length exceeds a single manufactured length. These joints typically do not include armor.

Factory acceptance test (FAT): These tests are conducted on completed cable lengths to demonstrate compliance with the specified requirements. FATs are often performed in the presence of the customer and the customer's representative or a third party nominated by the customer.

Flexible joints: A flexible joint is a mechanical and electrical connection designed to link two cable sections while maintaining the cable's flexibility, mechanical strength, and electrical integrity in the subsea environment.

Field joints: A field joint is used during installation or repair of subsea cable.

Fabricator: An individual or organization responsible for carrying out one or more of the following activities, as applicable: manufacturing, fabricating, assembling, erecting, inspecting, or testing.

Hang-off: A structure that securely holds the cable and attaches to the cable armor where it ascends to a platform, providing support for the weight of the hanging cable throughout the installation's lifespan.

Hold back structure: A structure designed to prevent dynamic tension propagation in the cable resting on the seabed.

Handover test: A test conducted when the responsibility for the cable transfers from one party to another, aimed at determining whether the cable sustained any damage during the previous process.

Hazard identification (HAZID): A risk analysis tool used to identify potential threats and hazards. Classification is based on the probability of occurrence and the potential consequences.

Hazard and Operability Analysis (HAZOP): A structured and systematic approach to examining systems and managing risks. HAZOP is commonly used to identify potential hazards and operability issues within a system.

Horizontal directional drilling (HDD): A mobile drilling rig configured to create a horizontally directed hole into which a duct is pulled before cable installation.

Inspection: The process of examining something to assess its condition, quality, or compliance with specific standards or requirements.

Internal design of joint: This design is intended to provide the electrical functionality of the joint by enabling current transfer, managing electrical stress, providing electrical screening, and protecting the insulation system from moisture ingress. The joint can be either rigid or flexible and may be designed for single-core or three-core configurations.

I-tube: A tube shaped like an "I" that is attached to the platform or foundation to facilitate, support, and protect the cable as it enters the platform.

Indoor termination: Installed in protected environments, such as switchgear rooms or substations.

J-tube: A tube shaped like a "J" that is affixed to the platform or foundation to support and protect the cable's vertical entry into the platform, the inclusion of a fixed angle at or above the cable's stated.

Manufactured length: The manufactured length is a continuous length of subsea power cable produced during an extrusion process or a portion thereof. It typically excludes factory joints or splices, except in cases where a joint is introduced due to a failure occurs during routine testing, in most cases, the manufactured length does not include armor, although it may sometimes include it.

Metal-enclosed GIS termination: Designed for gas-insulated switchgear (GIS) systems to connect cables in high-voltage, gas-filled environments.

Milliken conductor: A stranded conductor consisting of an assembly of shaped conductors, each lightly insulated from one another.

Marine survey: A survey conducted to assess the geophysical, geotechnical, environmental, and oceanographic conditions of a protected subsea power cable route or offshore energy infrastructure site.

Operating temperature: The range of temperatures within which a system, component, or material can function effectively under normal operating conditions. It typically refers to the minimum and maximum temperatures at which the equipment can perform its intended functions without risk of damage or reduced performance.

Outdoor termination: Exposed to outdoor conditions, providing protection against weather and environmental stress.

Offshore substation: A substation specifically designed to transform voltage from the collection voltage to a suitable transmission voltage, facilitating the efficient export of power to the onshore network.

Prequalification tests: These tests are conducted before the general commercial supply of a subsea cable system to demonstrate the system's satisfactory long-term performance. Prequalification tests are typically performed only once, unless there are significant changes to the cable system, such as modifications to materials, fabricating processes, design, or design levels.

Purchaser: The purchaser is defined as the entity that specifies and procures the subsea power cable system. This term typically refers to the client or end-user responsible for purchasing the system from a supplier or fabricator.

Rated AC voltage: For the voltage designation of cables $U_0/U(U_m)$, the definitions in IEC 60183 apply i.e.:

U_0 is the rated RMS power frequency voltage between conductor and earth or metal screen for which the cable is designed.

U is the rated RMS power frequency voltage between conductors for which the cable is designed.

U_m is the maximum RMS power frequency voltage between conductors for which the cable is designed.

Repair joint: A repair joint connects armored cable lengths and is typically used to repair damaged subsea cables or to join two delivery lengths, either offshore or in the factory.

Return cable: A return cable is a low/medium voltage DC cable used for the return current in monopolar operations of HVDC schemes. It can be connected along the entire length between the converters or only partially, linking a converter to an electrode station.

Routine tests: These are tests conducted by the fabricator on all produced components (cable lengths or accessories) to verify that they meet specified requirements.

Static cable: A cable designed for stationary applications after installation. It is engineered to mitigate loads from waves and currents, so they do not induce significant dynamic responses during operation.

Sample tests: Tests performed by the fabricator on samples taken from complete cables or components at a specified frequency to demonstrate that the finished products meet the required specifications.

Sea/land transition joint: The term "transition joint" typically refers to the connection between two different types of insulation. Specifically, a "sea/land transition joint" describes the interconnection between a subsea cable and a land cable, both having extruded insulation but differing in design. The transition joint is usually located on or near the shoreline.

Subsea cable system: Subsea cable system may include subsea cables, terminations, various types of joints and ancillary equipment.

Survey: Examination, investigation and gathering of information through various techniques. The term “survey” in this document is not to be construed as Classification related service provided by ABS.

Seabed Survey: a survey focused on geotechnical and geophysical investigations of the seabed soil properties and subsurface conditions along a subsea cable route or around offshore structures.

Service life: The service life is determined on a project-specific basis.

Test object: A test object refers to a cable length or accessory that is subjected to testing.

Test after installation: These tests are conducted to verify the integrity of the cable system once it has been installed.

Test loop: A test loop refers to a series of connected test objects undergoing simultaneous testing.

Type tests: Tests conducted prior to the general commercial supply of a specific subsea cable system to verify its satisfactory performance characteristics for the intended application. Once successfully completed, these tests do not need to be repeated unless there are changes to the cable or accessory materials, design, or fabricating processes that could impact performance.

Time-based maintenance (TBM), Preventive maintenance performed according to a predetermined schedule.

Transformer termination: Used to connect cables directly to transformers, often within substations.

Temporary termination: Used during testing, commissioning, or maintenance operations for short-term connections.

Very low frequency (VLF): An AC waveform with frequencies lower than 1 Hz, commonly used for high voltage tests on cable systems. A frequency of 0.1 Hz is typically associated with VLF, although voltage waveforms with lower frequencies may also be referenced.

Wet design: Wet designs do not have a metallic layer barrier to withstand the ingress of water.

15 Abbreviations and Acronyms

API: American Petroleum Institute

BS : Bend stiffener

CIGRÉ : Conseil International des Grands Réseaux Électriques (International Council on Large Electric System)

CIRIA: Construction Industry Research and Information Association

CLV: Cable laying vessel

CPS: Cable protection system

CPT: Cone penetrometer test-is a geotechnical method used to assess the engineering properties of soil.

DC: Direct current

DP: Dynamic positioning, dynamically positioned

DAS: Distributed acoustic sensing

DTS: Distributed temperature sensing

DOB: Depth of burial

DSS: Distributed strain sensing

DVS: Distributed vibration sensing

DOC: Depth of cover

EPR: Ethylene propylene rubber

EQ: Extended Prequalification

FAT: Factory acceptance testing

HAZID: Hazard identification

HAZOP: Hazard and operability

HSE: Health, safety, environment

HV: High voltage

HVAC: High voltage alternating current.

HVDC: High voltage direct current

ICPC: International Cable Protection Committee

IEC: International Electrotechnical Commission

IEEE: Institute of Electrical & Electronics Engineers

IMCA: International Marine Contractors Association

IMO: International Maritime Organization

IP rating: Ingress Protection Rating

ISO: International Organization for Standardization

ITU: International Telecommunication Union

ISIP: In-service inspection plan

ITP: Inspection and test plan

I3P: Independent third party

IMU: Inertial measurement monitoring.

kW: kilo Watt

KP: Kilometer Post (or Kilometer Point)

LV: Low voltage

MBR: Minimum bending radius

MEMS: Micro-Electro-Mechanical Systems

MV: Medium voltage

MML: Maximum mechanical load

MSP: Maximum service pressure

NDT: Non-destructive testing

O&M: Operation and maintenance

OTDR: Optical time domain reflectometer

PD : Partial discharge

PQ : Prequalification

PU : Polyurethane

PV: Photovoltaic

QA: Quality assurance

QMS: Quality management system

RMS: Root means square

ROV: Remotely operated vehicle

SCADA: Supervisory control and data acquisition

SOLAS: Safety of Life at Sea

TR-XLPE: Tree retardant crosslinked polyethylene

TB: Technical Brochure

T&I Plan: Transportation and installation plan

TDR: Time Domain Reflectometry

VLF: Very low frequency

UV: Ultraviolet

UXO: Unexploded ordnance

USBL: Ultra short baseline acoustic.

WTG: Wind turbine generator

XLPE: Cross-linked polyethylene

17 Reference

The references cited in this document include provisions that are directly invoked by specific references in the text. The primary requirements are based on the following standards and technical brochures: IEC 60502, IEC 60840, IEC 62067, CIGRE TB 490, CIGRE TB 496, CIGRE TB 852, CIGRE TB 623, CIGRE TB 862, and API 17E. In addition to these primary references, other documents are used to provide further technical context, best practices, and detailed guidance where applicable.

For dated references, only the edition cited applies, for undated reference, the latest edition of the referenced document applies.

17.1 ABS Publications

- ABS Requirements for Building and Classing Wind Farm Support Vessels.
- ABS Requirements for Offshore Substations and Electrical Service Platforms.
- ABS Requirements for Direct Current (DC) Power Distribution Systems for Marine and Offshore Applications.
- ABS Requirements for Nondestructive Testing.
- ABS Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installation.
- ABS Guide for Building and Classing Floating Offshore Wind Turbines.
- ABS Guide for Fatigue Assessment of Offshore Structures.

- ABS Guide for Building and Classing: Subsea Pipeline Systems
- ABS Guide for Classification and Certification of Subsea Production Systems Equipment and Components.
- ABS Guide for Dynamic Positioning System.
- ABS Guidance Notes on Global Performance and Integrated Load Analysis for Offshore Wind Turbines.
- ABS Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries.
- ABS Guidance Notes Equipment Condition Monitoring Techniques.
- ABS Guidance Notes on Subsea Pipeline Route Determination.
- ABS Guidance Notes on Cathodic Protection of Ships.
- ABS Guidance Notes on Independent Third-party (I3P) Services.

17.3 Industry Codes, Standards and Guidelines

Industry codes, standards, and guidelines have been divided into two sections: one listed below and the other referenced in Appendix 1.

- API 17E Specification for subsea umbilical.
- IEC 60502 Power cables with extruded insulation and their accessories for rated voltage from 1 kV (Um=1,2kV) up to 30 kV (Um=36kV).
- IEC 60840 Power cables with extruded insulation and their accessories for rated voltage from 30 kV (Um=36 kV) up to 150 kV (Um=170 kV)-Test methods and requirements.
- IEC 62067 Power cables with extruded insulation and their accessories for rated voltage from 150 kV (Um=170kV) up to 500 kV (Um=550 kV)-Test methods and requirements.
- IEC 63026 Submarine power cables with extruded insulation and their accessories for rated voltage from 6kV (Um=7.2KV) up to 60kV (Um=72.5kV)-test methods and requirements.
- CIGRÉ TB 490 Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30(36) to 500(550) kV.
- CIGRÉ TB 496 Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to 500kV.

SECTION 2

Plans and Data to be Submitted

1 General

This section outlines the documentation requirements for the evaluation and qualification of subsea power cables across all project phases, including design, fabrication, installation, commissioning, testing, operation and maintenance. Based on the documentation submitted, ABS can perform I3P design review for subsea power cable systems and review documents for I3P inspection in accordance with the ABS Guidance Notes on I3P services, as required by the contract or as otherwise mutually agreed in the scope of work. Upon completion of an I3P design review, ABS may issue an I3P Certificate in accordance with the ABS Guidance Note on Independent Third Party (I3P) Services.

3 Technical characteristics of cable and accessories

Cable fabricators are to provide the technical characteristics of the cable and accessories specified in 2/3.1, 2/3.3, and 2/3.5 for information (I) only. The mechanical and electrical properties of subsea power cables are to include the following:

3.1 Cable electrical characteristics

i) Fabricator information: Include the fabricator's name, cable type, designation, and fabricating date or code.

ii) Voltage Ratings: Provide U_0, U, and U_m values.

iii) Maximum installation depth: State the maximum allowable water depth for cable laying and operation.

iv) Conductor specifications:

a) Material type and nominal cross-sectional area (in mm²).

b) Conductor type (solid conductor class 1; stranded circular non-compacted conductor class 2; stranded compacted circular conductors; and stranded shaped conductor class 2, including keystone, Milliken etc.).

c) Construction and measures used to provide longitudinal watertightness.

d) Maximum design conductor temperature.

v) Insulation properties:

a) Insulation material and its nominal thickness.

b) Fabrication methods of insulation systems (e.g., extrusion, wrapping, curing method)

vi) Core sheath material and armor (if applicable):

a) Material type and nominal thickness.

b) Armor's material, layer count, lay direction, and wire diameters.

c) Thickness and material if additional metal tapes are used.

d) Type and thickness of outer serving material, if relevant.

e) Nominal thickness of any screen (metallic foil or metallic wires) and any semi-conducting layers, if relevant.

vii) Cable dimensions:

a) Nominal conductor diameter.

b) Nominal core diameter as applicable.

c) Nominal overall cable diameter.

d) Nominal inner and outer insulation diameters.

viii) Electrical attributes:

a) Nominal capacitance between the conductor and metal screen.

b) Calculated nominal stress at both the conductor and insulation screens.

ix) Metal screen/sheath:

a) Structural details and maximum DC resistance.

x) Over-sheath:

a) Compound type, nominal thickness, and any semi-conductive covering layer.

xi) Optical components (as applicable): Design and integration of optical elements.

xii) Fire performance (as applicable): Provide fire performance characteristics if the cable installation extends into topside/shore side hazardous areas, this requirement does not apply to underwater cable sections.

3.3 Cable mechanical characteristics

i) Cable type: Single-core, three-core, or other configurations.

ii) Armoring design: Single armor, double armor, or other.

iii) Torque balance: torque balanced or unbalanced cables.

iv) Physical properties:

a) Mass in air and water.

b) Cable diameter.

c) Squeeze load, sidewall pressure, and clamping pressure limits.

d) Maximum tensile force (with/without factory joints), if specified by fabricator, specifying maximum tensile force in handling, installation and storage.

e) Minimum bending radius for unarmored cores; minimum bending radius for complete cable in handling, installation and storage (if stated by the fabricator).

f) Bending stiffness (hysteresis curve showing bending moment to curvature relationship/ curve, stick-slip behavior).

g) Axial stiffness (tension/compression).

h) Torsional stiffness.

i) Temperature range for handling/installation.

j) Minimum coiling diameter (if applicable). Specify the minimum coiling diameter if the cable is expected to be stored, transported, or installed in a coiled configuration. The minimum coiling diameter is to comply with the cable fabricator's recommendations.

k) Maximum number of coiling operations.

l) Maximum allowable impact energy (e.g. for rock placement).

m) Coiling direction (clockwise/counterclockwise).

n) Maximum allowable compression.

o) Number of trans pooling cycles.

p) Distribution of tensile force between conductors and armor.

q) Allowable clamping force as applicable. Specify the allowable clamping force when the cable is to be secured using clamps during installation or operation, particularly in topside, J-tube, or dynamic applications. The allowable clamping force is to be provided by the cable fabricator and consider the mechanical properties of the cable, including armor type, sheath material, and allowable radial compression.

r) Crushing force as applicable.

s) Method to prevent longitudinal water penetration in conductor and under the metal screen/ sheath (for extruded cables).

t) Type of watertightness measures applied in the screen/sheath area.

u) List the test objects included in the cable system qualification or type testing program. This includes the main cable and any special components, such as bend stiffeners, bend restrictors, joints, terminations, and cable protection systems.

v) Tension-bending capacity curve, including utilization rates.

3.5 Accessories characteristics

i) Conductor connections within the accessories:

a) Assembly techniques, tooling, dies, and required settings.

b) Contact surface preparation and connector specifications (type, reference number, etc.).

c) Type test approval is applicable when the cable system includes accessories such as joints, terminations, or connections that are important to the electrical or mechanical performance of the system, especially when they are custom-designed or non-standard.

ii) Accessory testing identification

a) Cables in testing accessories that match the specifications.

b) Drawing illustrating all relevant tested features.

c) Fabricator's name and relevant accessory drawings.

d) Armor clamp specifications, where applicable.

e) Type, designation, and fabricating date or date code.

f) Insulation material type and dielectric fluid filling material type.

g) Type of outer protection

h) Sheath sectionalizing insulation if applicable

i) Consistent with cable characteristics, state the rated voltage.

j) Detailed installation instructions, including the document number or identifier of the installation instruction and issue or revision date.

iii) Current-carrying connections:

a) Detail the type, number, material, nominal cross-sectional area, nominal thickness, construction and water tightness for conductors and metal screen/sheath connections.

iv) Special requirements:

a) Gas immersed cable terminations, such as design pressure, insulation gas type, compatibility, and performance of termination insulators installed in switchgear.

b) Outdoor cable termination insulators, such as the MML value and the MSP value.

c) Ceramic outdoor termination insulators, such as the Maximum cantilever operating load in service, and design pressure if applicable.

5 Documents to be submitted

The documentation specified in this section for each phase of the cable system's lifecycle is to be submitted to ABS for review, approval, or information, as explicitly required herein or as otherwise mutually agreed in writing.

5.1 Design basis

The design basis specifies general requirements, main assumptions, design principles, methodologies and key parameters for cable system design. The design basis is to include all necessary overall design aspects and parameters applied in the calculations regarding the site external conditions, mechanical and electrical loads, load cases, safety factors for electrical systems and accessories, etc. The design basis is to be submitted for review and is to cover the following items:

i) Overall cable system description including general system arrangement, routing, requirements, boundary conditions, main assumptions, key operational parameters.

ii) Project stakeholders with responsibilities, plan and schedule.

iii) Function requirements.

iv) Site and service conditions at a specified offshore location, design value of site condition parameters with reference to the site condition.

v) Information from client specifications and requirements.

vi) Design methodologies and principles of cable systems.

vii) Overall description of the main electrical equipment and system to be installed.

viii) Codes and standards which form the basis for the project.

ix) Other relevant statutory, owner and local government requirements.

x) Quality management systems.

xi) Design lifetime of subsea power cable and associated system.

xii) Description of method and software/tools to be employed in the design calculations.

xiii) Design parameters for the external conditions.

xiv) Assumptions and acceptance criteria.

xv) Definition of mechanical and electrical design load cases.

xvi) Definition of technical interfaces.

xvii) Corrosion protection system if applicable.

xviii) Requirements for grid connection and power performance

xix) Procedures for load-effect analysis for the cable and associated components, including load type.

xx) Load-case matrices (including temporary conditions, installation, extreme conditions, fatigue conditions), design load and load combinations.

xxi) Other requirements, e.g. fabrication, load-out, transportation, installation, commissioning and testing as well as operation and maintenance that affect the subsea power cable design

5.3 Design

The design documents to be submitted are to include all relevant technical documentation necessary for the review and verification of the cable system.

The design process for subsea power cable systems includes the specification of cables, associated accessories, ancillary equipment, cable route, cable protection, and interface design at offshore asset and onshore landing points. This process is typically structured into two phases: the basic design phases, which establish key technical parameters and feasibility, and the detailed design phase, which finalizes engineering specifications, drawings and implementation plans. Depending on project-specific requirements and stakeholder expectations, this structure may be adapted. In some cases, the phases may be integrated or adjusted, provided that all key technical and operational aspects are comprehensively addressed.

5.3.1 Basic design

The basic design is to demonstrate that the subsea power cable design is structured and technically feasible, compliant with regulatory and industrial standards and capable of meeting client requirements before proceeding to the detailed design phase. During this phase of a subsea power cable project, the following aspects are addressed in the basic design documentation and submitted for review.

i) General description for cable storage, load-out, transport, installation, testing, commissioning, operation, and maintenance.

ii) Electrical system analysis (including short-circuit calculation).

iii) Thermal analysis.

iv) General cable system architecture (e.g. type of cable, number of cables, voltage ratings).

v) Surveys (such as site, route, geological/geophysical, and hydrographic etc.), as applicable on a project specific basis.

vi) Environmental study.

vii) Preliminary cable sizing, cable selection, cable handling, and cable specifications.

viii) Preliminary route definition and route selection.

ix) Analysis if applicable, see Section 3, Table 3.

x) Installation and cable laying methods.

xi) Equipment sizing and selection based on technical requirements.

xii) Preliminary design of key interface, such as substations, platforms, and onshore grid connections or others.

xiii) Crossing identifications and preliminary crossings designs where applicable.

xiv) Installation considerations and protection strategy statement.

xv) Develop preliminary layouts, diagrams and technical specifications.

xvi) Risk assessment and contingency measures.

5.3.2 Detailed design

The detailed design phase of a subsea power cable project involves the development of comprehensive technical documentation that addresses all engineering aspects, including calculations, drawings, fabricating specifications, and construction plans, from cable sizing to compliance testing. During the detailed design phase, the following aspects/documents are to be developed and submitted for review:

i) Detailed calculations/specifications of electrical, thermal and mechanical components.

ii) Material selection and specifications for conductor, insulation, sheathing, screen, armor, and corrosion protection.

iii) Drawings/design/specification of the cable system, including cross-sectional designs.

iv) Detailed design/drawing/reports of interfaces, including terminations, jointing, and transition points, intended to establish proper electrical and mechanical connections.

v) Detailed designs/drawings/reports of ancillary equipment and associated components such as clamps, bend-restrictors and hang-offs.

vi) Specification of fiber optical, including attenuation, bending loss and interface.

vii) Comprehensive protection strategies and material selection to prevent damage from external threats such as fishing activities or seabed movement.

viii) A cable handling manual includes detailing all cable parameters, tests, and limitations of cable handling

ix) Final route definition supported by route drawings, geospatial data, and seabed mapping to inform route planning and installation.

x) Crossing designs.

xi) Installation method statements and installation drawings outlining the step-by-step processes for laying and protecting the cable

xii) Installation layout drawings show the positioning and protection of the cable on the seabed.

xiii) If applicable, include packing analysis for transport and installation, with recommendation for transpooling.

xiv) Documentation on burial depth, protective measures, trenching and laying techniques, and vessel requirements for installation.

xv) Documentation covering regulatory compliance, testing requirements, and quality control processes.

5.5 Fabrication and testing

I3P service activities during fabrication are intended to verify that the fabricator complies with written specifications, detailed fabrication procedures, testing protocols, and relevant industry standards per fabricators' quality assurance and control procedures. For a specific subsea cable project, fabrication is to be conducted in accordance with the approved design and testing requirements.

The following documents are to be submitted for review:

i) Cable component specification and as-built drawing.

ii) Fabricating procedures.

iii) Quality control procedures and quality assurance plan.

iv) Inspection and test plan (ITP) or equivalent, covering all manufacturing steps from raw material supply to cable FAT, including reference procedures and acceptance criteria.

v) Raw material specifications and certification.

vi) Drawings of cable components.

vii) Material traceability procedures.

viii) Prequalification test procedures/reports.

ix) Type test procedure/reports.

x) Routine test procedure/reports.

xi) Sample test procedure/reports.

xii) Extension of qualifications test procedures/reports.

xiii) Factory acceptance test (FAT) procedures/report.

xiv) Calibration records/report.

xv) Final assembly and test report.

xvi) Records of any non-conformities and remedial/correction actions and their resolution and close-out.

xvii) Storage, handling and installation guidelines.

xviii) Traceability documentation.

5.7 Transportation

Transportation is to be planned to confirm that the offshore power cable system is transported within the design envelope conditions specified in 2/5.1. To prevent damage, a transportation plan and inspection and test plan (ITP) is to be developed based on the specified requirements outlined in the approved design. The transportation plan and ITP are to be submitted to ABS for review, to confirm alignment with the approved design.

The transport plan is to include the following aspects for review:

i) Introduction, overview of the transportation scope and objectives.

ii) Cable specification

a) Cable dimensions, length, weight, and electrical characteristics in cable description.

b) Cable handling requirement, describing the physical properties and handling requirement, see Section 5 for further details.

iii) Pre-transportation preparations

a) Suitability and motion study of cable transportation/installation vessel.

b) Navigation, positioning, and anchors/anchors handling equipment of cable transportation/installation vessel.

c) List items to inspect before transportation.

d) Operational limiting conditions (such as wind speed, wave height, temperature, timeline) for cable laying vessels.

e) Packaging instructions.

iv) Pre/post-transportation activities:

a) Testing procedures to be followed by the transportation contractor, including but not limited to DC resistance measurement and OTDR measurements for fiber optic cables, etc.

b) The transportation contractors are to be granted access to the cable manufacturing report and data book prepared by the fabricator, including records of all non-conformances (NCs) and details of repairs performed during fabrication.

c) Pre/post transportation inspection.

d) Risk management plan before transportation.

e) Inspection and testing plans (ITP), including pre/post-test and testing reports.

v) Transportation guidelines

a) Specifying approved methods of transportation (e.g. vessel, or other) in the transport options.

b) Limiting environmental conditions as defined by the design basis.

c) Loading and unloading procedures.

d) Instructions on how to properly secure the cable during transit.

e) Environmental considerations.

vi) Handling and storage

a) Handling equipment (e.g. cranes, or other).

b) Handling procedures, and checklists.

c) Cable load-out procedures.

d) Storage conditions (see Appendix 2 for further details).

5.9 Installation

The installation of the offshore power cable system is to be planned to confirm that the offshore power cable system is installed within the design envelope conditions specified in 2/5.1. To mitigate risks of damage, an installation plan and inspection and test plan (ITP) is to be developed based on the approved designs. The plan is to outline procedures for both normal and emergency operations, detailing each installation step and inspection process. Additionally, it is to incorporate the results of a risk management study (referencing IEC 31010 and ISO 31000 for further details), specifying control parameters and allowable tolerances during installation. The installation plan and ITP are to be submitted to ABS for review.

The installation plan is to include the following for review:

i) Introduction, overview of the installation scope and objectives.

ii) Cable specification.

a) Cable dimensions, length, weight, and electrical characteristics in cable description.

b) Cable handling requirement, describing the physical properties and handling requirement, see Section 5 for further details.

iii) Site preparation

a) Instructions for conducting a site inspection to confirm site readiness.

b) Guideline for preparing the seabed preparation where the cable will be laid.

c) Route clearance and preparations.

iv) Pre/post-installation activities

a) ITP, including pre/post-installation testing to confirm that the cable has not been damaged during installation.

b) Installation contractor is to be provided with access to the cable fabrication report and data book prepared by the fabricator, which includes all NCs, and repairs performed during fabrication.

c) Pre/post installation ROV or similar /inspection.

d) Pre/post-installation documentation and reports (including inspection report, drawing, test reports, GIS data).

e) Checklists.

v) Installation procedures

a) Cable installation analysis.

b) Risk management plan.

c) Installation vessel requirement.

d) List down the tools and machinery required for installation.

e) Methods for laying the cable on the seabed, landfall, infrastructure crossing.

f) Procedures/drawing for making joints and terminations.

g) Earthing evaluation.

h) Cable pull-in preparation and procedures.

i) Cable burial, and detailed protective measures, such as trenching, rock dumping, or mattressing.

j) Cable crossings.

k) Cable abandonment and recovery.

l) Procedures for monitoring the cable during installation and initial testing.

vi) Repair/remedial

a) Guidelines and proper procedure for repairs, remedial and troubleshooting in case of damage during transportation and installation.

b) The required qualifications of personnel are allowed to perform such repairs or remedial.

c) Tests after repairing/remedial.

5.11 Commissioning

During the subsea power cable commissioning phase, several key steps and checks need to be performed to confirm the cable has been correctly installed and commissioned. The following items are to be submitted for review:

i) Documentation:

a) Commissioning check list.

b) Inspection and test plan (ITP) for commissioning.

c) Commissioning procedures, manual, including cable termination, relevant drawings.

ii) Cable system testing as per 6/3.

iii) Final inspections and documentation.

5.13 Operation and Maintenance

When preparing for the operation and maintenance (O&M) of subsea power cables, several key documents need to be prepared to provide systematic and efficient management. These documents cover a wide range of aspects, from technical specifications and maintenance schedules to procedural guidelines. The following documents are to be provided for review:

i) Operation and maintenance plans/procedures. Refer to Section 7 for more details.

ii) In-service inspection plan (ISIP), including inspection and testing procedures.

iii) Maintenance/repair/remedial records and logs.

iv) Condition monitoring.

v) Risk management procedures, and emergency response.

vi) Training manuals/plans and qualification records.

SECTION 3
Design

1 General

This section outlines the key design requirements for subsea power cable, covering the cable system, cable selection, cable route, cable interfaces, and cable protection. These elements support the design and operation of subsea power cables in offshore environments.

1.1 Risk Assessment

A systematic risk assessment is required across all lifecycle phases of the subsea power cable system, including design, fabricating, storage, load-out, transport, installation, commissioning, operation, and maintenance. Its purpose is to identify potential risks, evaluate the impact of single or cascading failures and implement remedial actions to mitigate these risks.

The risk assessment is to consider not only the cable system itself but also related interfaces, such as connections to substations, terminations, adjacent subsea power cable, and other infrastructure. Both technical and operational risks are to be evaluated, including material degradation, electrical faults, mechanical stress, thermal stress and environmental challenges such as seabed shifts, marine growth, or extreme weather events.

The risk assessment is to address the following key areas:

i) Identifying risks to personnel during installation, operation, and maintenance, including vessel-based and diving activities.

ii) Assessing hazards such as cable damage that could cause environmental harm, while maintaining regulatory compliance.

iii) Evaluating risks of mechanical damage, electrical failure, or thermal overload that could impair system performance or disrupt operations.

The risk assessment process is to be methodical, with results guiding the development of mitigation strategies, contingency plans, and emergency response procedures. Reference ISO 31000 and ISO 31010 for applicable risk management techniques. All risks and actions are to be documented, tracked, and regularly reviewed to accommodate changes in design, operations, or regulations.

1.3 System design

The system design process for subsea power cables is an iterative process that spans multiple stages, starting with initial conceptualization and concluding with preparations for manufacturing, installation commissioning and O&M. This process requires close collaboration among various stakeholders, such as engineers, environmental experts, and regulators. The following is an overview of the key stages in the system design process:

i) Definition of project functional requirements: Establish the project's goals, technical requirements.

ii) Feasibility studies and conceptual design: Assess the technical and environmental feasibility, including route planning and selection of cable type.

iii) Basic design: Develop a basic design framework that incorporates electrical, mechanical, and thermal parameters, followed by preliminary analysis to confirm that the design aligns project requirements.

iv) Detailed design: Refine the design with specifications, including materials, dimensions, drawing and protection systems.

1.5 Functional requirements

The functional requirements outline the expected performance, characteristics, and operational conditions of the subsea power cable system, and provide guidance for its design, materials selection, fabricating, testing, installation, and operation. Key aspects for functional requirements include, but are not limited to, the following:

i) The scope is to include the quantity and type of cables, associated accessories, and ancillary equipment, as well as testing and acceptance criteria, and the required documentation.

ii) A list of applicable codes, standards, and regulations to be followed.

iii) Operating environmental conditions expected during the design life of the system, including temperature, pressure, and seabed conditions.

iv) Materials and components are to be suitable for the marine environmental conditions, with demonstrated resistance to water ingress, corrosion, and chemical degradation, and are expected to comply with corrosion control measures.

v) Design load requirements (mechanical, thermal, and electrical load) and relevant load combinations (e.g. tension, bending, hydrostatic pressure, thermal cycling).

vi) The system is to be designed to support installation, handling, recovery, reinstallation and maintenance, considering vessel capabilities, seabed conditions, and operational constraints.

vii) Mechanical and electrical interface requirements with connected systems, including offshore substations, termination, and joints.

viii) Project-specific requirements

a) The purchaser is responsible for defining any unique project-specific requirements applicable to the subsea cable system.

b) Custom design criteria may be developed for individual components of the cable system, specifying performance expectations across all lifecycle phases, from design and fabrication to installation and operation.

Below table is an overview of some components of cable systems and their design criteria for reference:

Table 1
Overview of Design and Acceptance Criteria for a Subsea Power Cable System

Component	*Design Criteria*	*Acceptance Criteria*	*Reference Standard*
Power Cables	- Rated for specified AC or DC voltage and frequency. -Continuous and emergency ampacity designed based on load profile, conductor temperature limits, burial depth, seabed thermal resistivity, and ambient seawater temperature, without excessive temperature rise or power loss. - Insulation system (XLPE, EPR, or Mass-Impregnated Paper) with sufficient thickness	- Compliance with rated voltage and current requirements. - Electrical continuity, insulation resistance, and AC/DC voltage withstand tests passed with no breakdown or partial discharge. - DC conductor resistance and electrical parameters within specified limits.	IEC 60287 IEC 60502 IEC 60840 IEC 62067 IEC 63026 IEC 60228 CIGRE TB 490 CIGRE TB 496

Component	*Design Criteria*	*Acceptance Criteria*	*Reference Standard*
	and dielectric strength to withstand operational, switching, and fault stresses. -Cable construction resistant to seawater ingress, corrosion, abrasion, and external mechanical damage. - Capable of withstanding installation loads including tensile forces, minimum bending radius, compression, and crushing. - Structurally stable and resistant to deformation under long-term hydrostatic pressure. - Where applicable, cable design is to be fatigue-resistant and suitable for dynamic and cyclic loading.	-Thermal performance verified by test or calculation in accordance with IEC methods. - Mechanical qualification tests passed, including tensile, bending, crushing, abrasion, and impact resistance. - Proven capability to withstand maximum subsea working pressure, temperature variation, and long-term corrosion exposure. - Fatigue tests passed where dynamic loading conditions apply.	CIGRE TB 623 CIGRE TB 852 CIGRE TB 722 CIGRE Electra 189 API 17E
Optical Cables	- Designed to meet required signal transmission and monitoring performance with minimal optical attenuation. - Fiber type, coating, and fiber count selected to suit operational, mechanical, and environmental requirements. -Resistant to seawater ingress, UV exposure (where applicable), and physical damage. - Suitable for expected subsea temperature range and hydrostatic pressure. - Capable of withstanding installation and operational tensile, bending, and compressive loads. - Controlled elongation behavior with adequate axial stiffness to limit fiber strain. - Provision for over-length management and strain relief. - Fatigue-resistant design where dynamic loading is expected.	- Optical attenuation, backscatter, and data loss verified within specified limits by OTDR and end-to-end testing. - Optical continuity maintained with no fiber damage. - Mechanical tests passed for tensile loading, bending radius, crushing, and impact resistance. - Verified performance under subsea conditions including seawater immersion, maximum working pressure, temperature cycling, and UV exposure where applicable. - Fatigue tests passed where required. - Fiber strain demonstrated to remain within manufacturer's allowable limits under combined mechanical and thermal loading.	IEC 60793 IEC 60794-1 IEC 60794-3 IEC 61757 CIGRE TB610 CIGRE TB 722 ITU-T G.652 / G.654/G.655 /G.976
Joints	- Designed to maintain low and stable electrical resistance or low optical loss throughout service life. - Fully sealed to prevent longitudinal and radial water ingress under maximum operating pressure. - Capable of withstanding installation loads and in-service mechanical, thermal, and pressure stresses. - Materials selected for long-term resistance to seawater corrosion and ageing. - Design suitable for subsea inspection, repair, or replacement where required.	- Hydrostatic pressure tests demonstrate no water ingress at maximum rated pressure. - Electrical resistance or optical attenuation across the joint within specified limits. - Tensile, bending, and pressure cycling tests passed without loss of integrity. - Materials verified for long-term seawater exposure. - Electrical or optical continuity maintained after qualification testing.	IEC 60502 IEC 60840 IEC 62067 IEC 63026 CIGRE TB 623 CIGRE TB 490 CIGRE TB 496 CIGRE TB 722 API 17E
Terminations	- Provide reliable electrical or optical connection with controlled electric stress distribution. - Prevent ingress of water, moisture, or contaminants where applicable. - Capable of withstanding installation and operational tensile, bending, vibration, and shock loads. - Fully compatible with associated cables, connectors, bend restrictors, and subsea equipment. - Thermal and mechanical compatibility with adjoining components.	- Electrical or optical continuity and voltage withstand tests successfully completed. - Sealing tests confirm no ingress of water or contaminants. - Mechanical load tests demonstrate resistance to installation and operational stresses. - Verified compatibility with subsea equipment interfaces and cable systems.	IEC 60502 IEC 60840 IEC 62067 IEC 63026 CIGRE TB 852 CIGRE TB 490 CIGRE TB 496 CIGRE TB 722 API 17E

1.7 Seabed survey and site investigations

The purpose of seabed survey and site investigations is to assess local conditions and the environment by gathering data for cable system design, installation, and protection requirements. Refer to CIGRE 883 for more detail, The following activities in Table 2 are to be conducted during the concept and engineering phases:

Table 2
Seabed survey and site investigation activities

Survey Type	*Purpose*	*Key Activities*
Preliminary Marine Survey	Initial assessment of seabed conditions	Review existing data, bathymetry survey, identify sediment types and obstacles
Geophysical Survey	Mapping of seabed for cable routing	Conduct bathymetric survey, sub-bottom profiling, side-scan sonar, magnetometer
Geotechnical Survey	Determine soil properties and seabed characteristics	Gravity Core, Vibrocore (VC), Cone Penetration Testing (CPT), borehole sampling
UXO (Unexploded Ordnance) Survey	Identify and clear potential UXO hazards	Magnetometer survey, target identification and investigation, UXO clearance planning
Landfall & Intertidal Survey	Assess cable landing and nearshore conditions	Survey shoreline stability, sediment transport analysis, evaluate access constraints
Environmental Survey	Evaluate ecological and environmental impact	Marine habitat mapping, water and sediment sampling, protected species assessment

1.9 Site conditions

Subsea power cable systems are designed to operate under a range of site-specific conditions, where environmental factors play a significant role in determining the selection of cables and associated accessories. Site condition data forms the basis for evaluating all phases of the cable's lifecycle, including the design, transportation, installation, commissioning, testing, maintenance and operation. This data is collected through a combination of investigative techniques, including geological studies, geophysical surveys, geotechnical investigations, environmental studies, laboratory testing and detailed analysis.

Design parameters derived from site conditions are fundamental for developing subsea power cable systems. The following site-specific conditions are to be considered in the design process:

i) Wind conditions.

ii) Marine/metocean conditions and bathymetry.

iii) Seismic activity (earthquake risk).

iv) Electrical power network conditions (refer to IEC 61400-3-1 for detail).

v) Geotechnical conditions of the seabed or ground.

vi) Environmental factors, such as waves, currents, water levels and marine growth, etc.

vii) Additional environmental factors, including temperature fluctuations, sediment movement, and any pre-existing subsea structure.

1.11 Electrical system analysis

Cable fabricators can design, construct, and test cables in accordance with relevant industry standards (see 4/5) before performing an electrical system analysis. For specific projects, an electrical system analysis is to be conducted, for new or existing cables, to demonstrate that the cables meet design requirements.

The design is to incorporate applicable grid connection compatibility code requirements if the system is connected to the shore grid, considering the ratings of power plants, export-circuit components, and including necessary protection measures. These elements are to be verified through detailed system design analysis.

The electrical system analysis is to be included in the scope of the overall electrical design analysis. It will provide input to establish the required electrical parameters for the subsea power cable system under the specified design, operating and service conditions and for the planned installation methods. This analysis is to cover the following key areas for subsea power cables:

i) Current-carrying capacity calculations.

ii) Short circuit calculation.

iii) Thermal analysis.

iv) Insulation coordination.

v) Harmonic analysis.

vi) Transient stability analysis.

vii) Earthing (grounding) study.

viii) Operating temperature range.

ix) Performance evaluation under service conditions.

For specific projects, the following parameters are to be identified based on the electrical system analysis and in coordination with stakeholders:

i) AC or DC system configuration.

ii) Single core or three core cables.

iii) System operating voltage.

iv) Expected voltage drop over the subsea power cable length.

v) System frequency (for AC system).

vi) Maximum rated current for both continuous and emergency operation.

Electrical system analyses are to be performed in accordance with IEC 60287, IEC 60949, IEC 60853, and IEC 60071, as applicable to the system voltage and AC or DC configuration. These analyses are to be supplemented by relevant CIGRE documents for subsea applications, as listed in Table 1, and 1/17.3.

Accessories used in each application are required to have rated voltage consistent with the cable's rated voltage and be suitable for the intended operating conditions. Symbols indicating the voltage of power cables and accessories are to be applied in accordance with IEC 60183.

3 Cable system

The cable system is to be designed to comply with the functional and technical requirements specified in this document and mutually agreed upon by the fabricator and purchaser. This section outlines the requirements for power cables, optical cables, accessories, and ancillary equipment.

3.1 Power cable

Subsea power cables can be categorized into various types as specified in 1/3, Table 1. Regardless of the classification, all power cables are expected to meet the electrical, thermal, and mechanical requirements necessary for their intended operational conditions, these requirements are to be defined by either the fabricator or purchaser, or through collaboration between both parties, based on the specific needs of the project, where applicable.

3.1.1 Electrical requirements

Key electrical parameters for subsea power cables—such as operating voltage, frequency, short-circuit ratings, and current-carrying capacity, expected voltage drop—are to be established by electrical system analysis. Additional electrical characteristic parameters, such as minimum conductor cross-sectional area, insulation thickness, resistance, inductance, capacitance, and derived characteristics like series impedance and losses, are to also be determined for the cable.

The conductor's design is to meet these electrical requirements to provide the necessary current-carrying capacity for the expected load. Subsea power cable conductors, typically made from copper or aluminum, may be configured in various forms based on application needs, such as solid, stranded, compact, compressed, flexible, Milliken, or keystone-shaped designs.

Material selection for conductors is to consider mechanical strength, flexibility, corrosion resistance, weight and water penetration and propagation. Conductor core design is to follow Section 5 of IEC 60228 for material requirements and Section 6 for conductor resistance, as applicable, to support specific project requirements.

For further guidance on cable conductors, refer to the relevant IEC 60228 standard and CIGRE TB 610 publications.

3.1.2 Thermal requirements

The cable system is to be designed to meet the worst-case thermal loads. Bottlenecks in the cable system, such as J-tubes, buoyancy modules, bend stiffeners, on-bottom stability equipment and other locations, are to be evaluated individually, as applicable. The temperature does not exceed the thermal limitation for any materials in the power cable. The thermal analysis is to be conducted for subsea power cables exposed to elevated temperatures, either internally or externally. The analysis is to evaluate the steady and transient state temperature distribution across the cable cross-section. The fabricator is to demonstrate that the local layers maximum temperatures in the cable are within all materials limits at the specified environmental and loading conditions. The thermal requirements for offshore subsea power cables typically involve the following key parameters to be considered:

i) Current carrying capacity, including maximum electrical load.

ii) Expected operating frequency range as applicable.

iii) Thermal resistivity of surrounding medium (soil thermal resistivity, thermal conductivity).

iv) Environmental temperature (seabed temperature, seawater temperature and air temperature), and seawater currents.

v) Cable installation depth.

vi) Heat conductivity and heat dissipation methods (water, thermal backfill material).

vii) Thermal properties of the materials surrounding the cable, such as seabed soil or water.

viii) Cyclic loading effects (peak load and continuous load).

ix) Thermal stability and thermal diffusivity.

x) Allowable operating temperature range, including the highest operating temperature.

xi) Cable storage temperature.

xii) Cable transportation, load out and installation temperature.

xiii) Insulation and sheathing materials.

Standards such as IEC 60287-1-1 provide the fundamental equations and methods for calculating the continuous current-carrying capacity of cables, considering relevant thermal factors. Thermally permissible short-circuit currents are to be calculated in accordance with IEC 60949, Clauses 2-6, including non-adiabatic heating effects.

3.1.3 Mechanical requirements

A subsea power cable is to be designed to withstand mechanical forces throughout its full lifecycle, covering stages such as fabrication, storage, transportation, installation, commissioning, testing, operation, and maintenance. The design is to account for site conditions, installation techniques, and operational environments. Mechanical design requirements, both static and dynamic, are fundamental to support the subsea cable's durability and performance across various operating conditions.

For environmental conditions, refer to 3/1.9 as applicable, for other more detailed guidance, refer to CIGRE TB 610 and TB 862 as well as ISO 13628-5 and API 17E, where relevant.

The following key parameters of project-specific design requirements are to be addressed in the mechanical requirements of subsea power cables:

i) Maximum tensile force, including maximum tension during handling, installation and maximum tensions at specific bending radius.

ii) Cross-sectional arrangement.

iii) Lay-up.

iv) Sub-bundles (as applicable).

v) Weight.

vi) Minimum bending radius for complete cable.

vii) Axial stiffness.

viii) Bending stiffness.

ix) Torsional stiffness.

x) Maximum crush load, squeeze load, crush (radial squeeze), short term or long-term.

xi) Impact (mechanical, external).

xii) Abrasion.

xiii) Friction factors.

xiv) Coiling direction and minimum coiling diameter (as applicable).

xv) Bending without tension.

xvi) Sidewall force.

xvii) Bending fatigue.

xviii) Thermal fatigue.

xix) Creep.

xx) Corrosion.

xxi) Compression capacity.

xxii) Kinks/minimum bottom tension.

xxiii) Reeling tension.

xxiv) Short circuit force.

xxv) Radial water pressure/penetration.

xxvi) Longitudinal water penetration.

xxvii) Length marking.

Mechanical analysis is required to assess the feasibility of a subsea power cable and to identify technical challenges during installation and operation. The analysis is to include environmental conditions (such as temperature, pressure, and water currents), service conditions (including operational loads and cable movement), and other parameters that affect long-term functionality. Material properties and potential degradation mechanisms are to be identified, evaluated for their impact on cable integrity, and addressed through design and installation procedures.

The specific types of analysis required depend on the project's development stage. In the early design phase, typically, more theoretical and simulation-based analyses may be required, while later stages may involve practical evaluations and real-world testing. These analyses are to support early identification of issues, reduce risks, and improve the design and installation approach.

The following table outlines the mechanical analysis requirements for the subsea power cable system, highlighting the key areas to be evaluated at each stage of development.

Table 3
Overview of Analysis Requirements for a Subsea Power Cable System

Analysis Type	*Design Criteria*	*Acceptance Criteria*	*Reference Standard*
Global Analysis	Evaluate static and dynamic load effects from installation, environmental conditions, and seabed interaction. Evaluate cable response to environmental loads (waves, currents, position, motions) and operational conditions (laying, operation). Include cable configuration, tension, and curvature.	Stress/strain/force/tension/ position are within allowable limits; no buckling or excessive bending; and the minimum bend radius requirement is not violated.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
Local Analysis	Assess stress concentrations at bend restrictors, hang-offs, touch-down zones, etc. evaluate local stresses and strains in cable components (conductors, insulation, armor) under combined loads (tension, bending, torsion).	Local stresses/strain remain below yield strength, no plastic deformation. No local damage to cable layers under design loads	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
On-Bottom Stability Analyses	Evaluate cable stability on the seabed under hydrodynamic loads and environment loads. Consider soil interaction and cable weight, seabed friction, embedment.	Cable remains stable on seabed during operational and extreme events, lateral displacement within allowable limits.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
VIV (Vortex-Induced Vibration) Analyses	Evaluate cable response to vortex shedding under steady current conditions. Assess VIV induced fatigue life.	No resonance or excessive vibration, and fatigue life is not affected, and fatigue damage within acceptable limits.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
Interference Analyses	Assess interactions with other cables, pipelines, or installations under static and dynamic environmental loading. Consider clearance and contact scenarios.	Minimum required separation maintained. No adverse interaction under design conditions.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
Free-Spanning Analyses	Evaluate static & dynamic response of unsupported cable spans. Assess VIV of free spans in steady current and to establish curvature and sag behavior.	Stress limits met, no excessive sag or fatigue damage. Spans	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.

Analysis Type	*Design Criteria*	*Acceptance Criteria*	*Reference Standard*
		within acceptable limits, fatigue life verified.	
Installation Analysis	Evaluate cable behavior during installation (tension, bending, crushing force) and define operational lay limits. Consider vessel capabilities and environmental conditions.	Installation parameters remain within allowable limits for tension, force, curvature, bend radius, internal pressure, crushing and squeezing loads, and acceptable laying conditions were maintained throughout the installation process.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
Pull-In/out Analysis	Evaluate cable tension and bend during pull-in to the I/J-tube or platform and during pull-out operations, under dynamic and static conditions. Account for axial and lateral soil resistance and curved routing sections.	Pull-in/out forces within design capacity, no overstress or structural damage. Retrieval forces within acceptable limits; no damage to cable/sheath. Controlled tension with no overstress or damage to cable or sheath.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
Structural Analyses	Evaluate load cases from installation, operation, and accidental conditions. assess cable structural integrity under operational and extreme loads (tension, compression, bending).	No permanent deformation. Structural integrity is maintained under all load cases. Stress/strain within allowable limits; no buckling or kinking	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.
Fatigue Analysis	Assess cyclic loading from waves, currents, VIV, and operational loads. Consider stress concentration points and cumulative damage.	Fatigue life meets design requirements, No fatigue-induced deformation and failure within the design life.	API 17E, Section 6, Annex C.API 17 J. CIGRE 862, Section 3.

i) Dynamic cables

Dynamic subsea power cables are deployed in environments where continuous movement occurs—such as floating wind turbines or offshore floating platforms. These cables are subject to repetitive bending, dynamic forces, and tension loads over time. Such mechanical stress strongly influences the cable's design, particularly the configuration and characteristics of its cross-sectional components.

Key mechanical design requirements for dynamic cables:

a) Fatigue resistance

Dynamic cables are designed to endure repeated bending and tension cycles throughout their operational life.

b) Cable configuration

Dynamic cables connecting floating assets to the seabed affecting stress distribution, fatigue life, and structural interactions. Key design factors, including cable length, curvature, and tension forces, are to be evaluated with respect to environmental conditions. Additionally, the interaction between the power cable and floating substructure, as well as the mooring system, is to be fully considered.

c) Ancillary equipment

To support and protect the cable, some ancillary equipment is integrated:

1) Bend Stiffeners: Prevent excessive bending near terminations.

2) Buoyancy Modules: Provide uplift and help maintain the desired cable shape.

3) Hang-offs and Clamps: Secure the cable to platforms and subsea structures.
These components introduce additional mechanical loads and potential failure points, making their design and integration highly significant.

d) Marine growth
Biofouling increases the cable's weight and alters its mechanical properties; these effects are to be accounted for in both design and analysis.

e) Structural analysis
Perform both global (system level) and local (component-level) analysis:

1) Global analysis: Simulates environmental loads, platform motion, and overall cable dynamics.

2) Local analysis: Evaluates stress concentrations, fatigue life, and mechanical integrity of individual components.

f) System integration
As illustrated in Figure 2, the dynamic cable system includes the cable, connectors, joints, and support structures. These elements are to be engineered to maintain system integrity and prevent failures originating from accessories.

ii) Static cables
Static subsea power cables are installed directly on the seabed and remain stationary throughout their service life. They are commonly used for interconnecting between offshore platforms or between offshore and land-based facilities.
Key mechanical design requirements for static cables:

a) Seabed conditions: Assess seabed characteristics for stability, burial depth, and protection against external damage.

b) Environmental loads: Design to withstand environmental force including current, wave action, and temperature variations.

c) Installation stress: Cables are required to withstand mechanical stress during laying and burial, Proper planning and equipment selection during installation are necessary to avoid damage.

d) Protection measures:

1) Armoring for abrasion and impact resistance.

2) Burial or trenching to prevent damage from anchors or fishing gear.

The following factor, as determined through calculation or testing, is to be used during the design phase unless otherwise agreed upon by the fabricator and purchaser.

a) The safety factor on fatigue life for the subsea power cables is to be no less than 10 as outlined in this document.

b) Typical parameters for global and local analysis are provided in Section 5.3 of CIGRE TB 862 or API 17E, including environmental data, motion characteristics, mooring system details, hang-off position, water depth, cable properties, return period, etc.

3.1.4 Test requirements

The tests outlined in this document are to align with the project-specific requirements, special tests, the potential risks of the intended application and the feasibility of the testing program and strictly as a minimum requirement. All tests conducted on cables and their related accessories are to be documented. The choice of testing methods and acceptance criteria is to follow relevant industry standards. For specific projects, testing scope and criteria are to be mutually agreed upon by the purchaser and fabricator, considering the possible hazards associated with the application and the feasibility of the testing program. Below are the typical tests for the cable system, with detailed descriptions of each test provided in the subsequent Section 4.

i) Development tests, see 4/7.15.

ii) Route Tests.

iii) Sample tests.

iv) Type tests.

v) Prequalification test.

vi) Extension of qualification tests.

vii) Electrical test after installation.

Tests on optical fibers are typically performed at four stages:

i) Fabricator test of optical cable.

ii) Tests of optical cable after transportation.

iii) Tests of optical cable after installation.

iv) Commissioning test of optical cable system.

Mechanical testing of subsea cables for dynamic cables refers to ISO 13628-5, API 17E and CIGRE TB 623 and CIGRE TB 862 as applicable.

A Factory Acceptance Test (FAT) is to be carried out.

3.3 Optical fibers

Fiber optic cables are mainly used for communication and monitoring over long distances with minimal loss in transmission. Optical fibers can be integrated into the interstices of three core power cables or installed in the bundle with subsea cable or separately. When installed separately or in a bundle with single core power cable(s), the optical fiber is to be armored to provide mechanical strength. Design of optical fibers for subsea applications is to consider the following items:

i) Fiber type: The table below provides an overview of typical optical fibers for subsea applications.

Table 4
Typical optical fibers for subsea power cables

Type	*Wavelength (nm)*	*Use case*
Communication	1310; 1550 *	Short/medium/long distance communication
Monitoring (Temperature/strain/ vibration/fault detection)	1310/1550/ 1625/1650 *	OTDR/DTS/DAS

Note: * Other wavelengths are available.

ii) Fiber count: the cable contains the required number of optical fibers depending on the application, and plus some spare fiber.

iii) Attenuation: the fibers are to exhibit low attenuation to maintain signal transmission.

iv) Typical construction layers of fiber optic from inside to outside: optical fibers, primary coating, buffer tube, water blocking layer, strength members, central strength member, inner sheath, armoring, outer sheath.

Additional information about optical fibers can be found in IEC 60793, IEC 60794, IEC61757, CIGRE TB 610, ITU-T G.652.D, ITU-T G. 654, and ITU-T G.976.

3.5 Cable accessories

The design of cable accessories is expected to comply with the functional requirements specified in 3/1.5. All cable accessory designs are to provide compatibility with the mechanical, electrical, and performance requirements of the cable system, as well as its operating conditions. Additionally, these designs are to adhere to the same functional requirements and standards as the cable system itself. The subsea cable accessories are to be constructed to limit the consequences of faults in the water barriers. Compatibility of cable accessories can be verified through electrical type approval testing, supported by additional evaluations such as tests listed in 4/7.9, to maintain their performance.

3.5.1 Joints

Subsea cable joints provide an insulated and fully protected connection between two or more cables, providing electrical continuity and mechanical stability within the cable network. The choice of joint type depends on the specific application and system requirements. Cable joints can generally be categorized as follows:

i) Factory joints.

ii) Field joints, such as repair joints, splice joints.

iii) Sea/land transition joints.

iv) Flexible joints, used in dynamic environments.

v) Branching joints.

All joint designs, regardless of type, are to meet the following requirements:

i) The contact resistance of connections is to remain within the approved design limits.

ii) Electrical insulation properties match the original cable.

iii) The joint withstands short-circuits currents to prevent damage during fault conditions.

iv) The joints withstand installation and operational loads, including tensile forces during laying and compressive forces in subsea environments.

v) Tolerate bending radii as specified in cable design.

vi) Provide flexibility and durability for dynamic environments to support performance under vibrations or repeated mechanical strain.

vii) Match or improve upon the cable's thermal performance to avoid hotspots.

viii) Suit the cable's rated operating and emergency temperatures without degradation.

ix) Completely seal the joint to prevent water ingress, even under hydrostatic pressure at the target installation depths.

x) Use corrosion-resistant materials to maintain protection in marine environments.

xi) Incorporate sealing mechanisms to protect insulation and internal components from water penetration or external contaminants.

xii) Maintain the insulation integrity of the cable's outer sheath by insulating the metallic shell or screen wire connections from earth potential.

xiii) Withstand operational stresses, such as vibration, mechanical strain, thermal expansion and high-water pressure if the joint is in water.

xiv) Joints are not allowed in the dynamic section of the subsea power cables.

3.5.2 Terminations

Termination forms the connection point between a cable and other electrical equipment, such as transformers, switchgear, or busbars, providing electrical continuity and mechanical stability. Various types of terminations are used depending on installation environments and system configurations. Common types include:

i) Metal-enclosed GIS termination.

ii) Transformer termination.

iii) Outdoor termination.

iv) Indoor termination.

v) Temporary termination.

All termination designs, regardless of type, are to meet the following requirements:

i) Contact resistance of termination connections does not exceed the approved design limits.

ii) The termination's insulation meets the same performance standards as the cable, including electrical strength, durability, and resistance to degradation over time.

iii) Adequate mechanical support is to be provided to prevent sagging, bending, or undue strain on the cable.

iv) Endure mechanical stress from thermal expansion, wind, ice accumulation, and busbar load without compromising structural or electrical integrity. The safe working load for terminations may differ from the limit state of subsea power cables.

v) The termination is designed to withstand short-circuit currents during faults.

vi) The termination is needed to protect the cable insulation and sheath from atmospheric moisture and prevent the ingress of pressurized dielectric liquids or gases from adjacent equipment, such as metal-clad busbars.

vii) Designs are to account for temperature effects during transport, installation, and potential repair or intervention scenarios after prolonged immersion.

viii) The design documentation is to specify whether the termination and cables are intended for internal free flooding.

ix) Compatibility of nonmetallic materials with permeated fluids is to be documented for subsea terminations.

x) Topside terminations are expected to accommodate fluids and gases emerging through the cable interstice as applicable.

xi) Continuity or insulation is to be incorporated between the cables, accessories, and interfacing hardware as required for the overall corrosion protection system.

xii) Corrosion protection through coating is to be designed to meet the service life standard agreed upon with the purchaser.

xiii) Cathodic protection is to be implemented in accordance with ISO 12473 (or equivalent).

xiv) Terminations are to be designed to endure long-term operational stresses, such as vibration and temperature fluctuations, to achieve consistent performance and reduce maintenance needs.

3.7 Ancillary equipment

The design of ancillary equipment is to meet the functional requirements detailed in 3/1.5. These components are to be designed to withstand the anticipated loads they will encounter, recognizing that the safe working load (SWL) for these components may differ from the limit states of the subsea power cable. Ancillary equipment fabricators are expected to provide relevant data to all stakeholders.

The design is to also account for temperature variations during transportation and installation, and consideration is to be given to the selection of installation methods and any potential repair or intervention scenarios.

Design documentation is to specify whether the components are intended for intentional free flooding, as applicable.

Additionally, ancillary equipment is to be integrated into the overall corrosion protection system, Coatings are to be designed to meet the agreed service life, cathodic protection is to comply with ISO 12473 (or equivalent).

For free-span connections between the J-tube bell mouth or subsea termination interface and the seabed, the design is to comply with the project-specific design basis and the requirements outlined in 3/1.5.

If isolation valves or electrical/optical short/test points are included in the design, they are to be accessible and operable in accordance with the fabricator's documented specifications.

For subsea cables intended for temporary lay-down or wet storage, an evaluation is to be conducted to determine the need for pressure relief during retrieval. Additional corrosion protection may be required in such cases. When temporary end sealing is used, a double watertight barrier is to be incorporated to provide watertight integrity.

Typically, ancillary equipment includes the following:

i) Bend stiffeners.

ii) Bend restrictors.

iii) Bell mouths.

iv) Buoyancy modules and ballast modules.

v) Hang-off

vi) Subsea buoys.

vii) Tethers for subsea buoys and tether clamps.

viii) Riser and tether bases.

ix) Subsea buoy clamps.

x) Tether clamps.

xi) Repair clamps.

xii) I/J tube seals.

xiii) Pull-in heads/installation aids.

xiv) Load-transfer devices.

xv) Mechanical protection.

xvi) Fire protection.

This document does not provide detailed requirements for all the listed ancillary equipment; some are covered in the following section. For additional requirements related to ancillary equipment, such as design consideration, safety factor, material selection, analysis, testing, fabrication, and installation, refer to API 17E, API 17L1 and API 17L2.

3.7.1 Hang-off

Hang-offs are installed on offshore assets to anchor and secure subsea cables at designated points, such as the top of I-tubes, J-tubes, or other cable entry locations. These systems are designed to withstand both static and dynamic tensile loads resulting from offshore asset movements and installation forces. The design facilitates the transfer of maximum tensile loads without causing damage to the cable or its components, allowing the hang-off system to remain functional and durable throughout its operational life.

Functional requirements include:

i) Armor wires are to terminate at the hang-off, while electrical and optical elements are to pass through and terminate separately.

ii) The design is to facilitate access for inspection and maintenance of hard-to-reach areas (e.g., tops of I- or J-tubes) after installation, with provisions to prevent long-term corrosion or creeping in load-bearing components.

iii) During hook-up at the top side facility, the system is designed to permit controlled pressure release within its design limits.

iv) Hang-offs are expected to offer the required strength and fatigue resistance subject to operational movement.

Below table lists design requirements for hang-offs.

Table 5
Design Requirements for Hang-offs

Category	*Design Conditions*	*Acceptance Criteria*	*Reference Standard*
Loads and load combinations	-Short term operation -Expected operation -Abnormal operation	- Support all weights without excessive deflection or failure. - Withstand wave forces (dynamic and static). - Account for wind effects on the system. - Tolerate normal operational tension/ compression without permanent deformation, (e.g., maintain than minimum bunding radius. - Absorb operational impact forces without structural damage. - Resist maximum loads without failure (including extreme accidental conditions). - Withstand the expected number of fatigue cycles without failure.	API 17E, API 17L1, API 17L2
Maintenance access	Normal and unplanned maintenance	- Provide access for inspection and maintenance, with monitoring points for cable condition.	API 17E, API 17L1, API 17L2
Temperature effects	- Thermal expansion and contraction. - Differential temperature between	- Materials selected are to tolerate expected temperature fluctuations without failure. - Design is intended to minimize stress and deformation caused by temperature gradients.	API 17E, API 17L1, API 17L2

Category	Design Conditions	Acceptance Criteria	Reference Standard
	internal and external environments.		
Material properties	- Environmental exposure (e.g., corrosion, wear)	- Use corrosion-resistant materials and wear-resistant materials suitable for service conditions.	API 17E, API 17L1, API 17L2

3.7.2 Bend Stiffeners

Bend stiffeners protect subsea cables by preventing excessive bending, particularly at transition points (e.g., hang-offs). They help maintain the required minimum bending radius to reduce risk of damage to internal components, even under extreme operational conditions.

Types of bend stiffeners:

i) Dynamic bend stiffeners:

a) Designed to handle combined tension and dynamic loads, including riser-tube angles and operational temperatures.

b) Documentation of dimensions, mass, and center of gravity is required for handling procedures.

c) The design is to support attachment via flanges or latches and facilitate detachment during maintenance, major overhauls, or decommissioning.

ii) Static bend stiffeners:

a) Intended to increase bending stiffness at attachment points, especially for armored cables.

b) Applicable to configurations such as repair joints, providing smooth transitions to reduce the risk of damage during installation or recovery.

Below are key design requirements for bend stiffeners:

Table 6
Design Requirements for Bend Stiffeners

Design Requirement	Design Criteria	Acceptance Criteria	Reference Standard
Loads and load combinations	- Support operational, installation and environmental loads. - Withstand dynamic and static wave forces across sea states. - Handle normal operational tension/ compression and extreme loading scenarios. - Absorb both operational and accidental impacts (e.g., vessel collision). - Resist deepwater pressure at varying depths and conditions. - Withstand fatigue due to cyclic VIV and operational conditions. - Account for accidental loading conditions (e.g., extreme weather, impacts).	- Bend radius of the bend stiffener meets the approved design and satisfies the minimum bending radius for the specific tension and angle combination during installation, operation, and recovery. -Maximum strain within the BS PU is verified. - Fatigue testing is to continue beyond the specified cycle count until the bend stiffener reaches failure.	API 17E, API 17L1, API 17L2

Design Requirement	*Design Criteria*	*Acceptance Criteria*	*Reference Standard*
	- The system is expected to endure the anticipated number of fatigue cycles under operational conditions.		
Thermal Effects	- Account for temperature variations from operational or environmental factors. - Accommodate internal and external temperature differences. - Operate within the specified temperature range.	Design accounts for thermal expansion and contraction without structural failure.	API 17E, API 17L1, API 17L2
Material Selection	- Consider environmental exposure (e.g., corrosion, wear).	Use high-strength, durable, corrosion-resistant materials suitable for long-term service.	API 17E, API 17L1, API 17L2

3.7.3 Pull-in head

A pull-in head is used to pull cables along the seabed or through I-/J-tubes and is expected to withstand installation loads without causing damage to the cable or its components. Minimum design requirements include:

i) Support smooth passage over rollers, sheaves, and through risers without snagging.

ii) Incorporate recessed or flush-mounted bolts, fasteners, and pad-eyes, with all attached components remaining within the pull head's outer diameter.

iii) Provide corrosion protection suitable for extended subsea exposure.

iv) Seal electric and optical-fiber cables against seawater ingress, especially for long-term deployment.

v) Being classified as lifting equipment, with provisions for swivels or stackable configurations to accommodate limited overhead clearance.

vi) Comply with stress criteria applicable to metallic tubes and undergo purchaser-approved proof testing either prior to or following cable connection.

3.7.4 Bend Restrictors

Bend restrictors are designed to prevent subsea cables from exceeding a specific bend radius by locking out, providing stability during handling and maintaining cable positioning throughout service life.

The design is to accommodate expected combinations of load and angular displacement during installation, operation, and recovery. Considerations include size, mass, center of gravity, ageing effects, and potential failure modes of end fittings. For dynamic cable installations, special attention is to be given to risks such as low-cycle fatigue, especially during load-out, deployment, and pull-in activities where repeated cycles may occur. The design is to also account for external influences, such as free-span corrections, rock placement, and additional bending moments introduced by components like bend restrictors.

Materials used in bend restrictor elements such as elastomers, fiber-reinforced plastics, or metals are to be selected based on their compatibility with the operational environment and their ability to resist corrosion over the intended service life.

To support protection, mechanical safeguards may be employed during handling to prevent physical damage to the cable.

3.9 Construction of cables

Subsea cables typically consist of multiple layers, each serving a specific function to maintain structural integrity, durability, insulation, and protection, depending on the intended application and environmental conditions. Key components of subsea power cables include:

i) Conductor

a) The current-carrying conductor is to be made of either copper or aluminum.

b) The conductor's cross-sectional area is directly proportional to the power demand of the system and is to meet the functional requirements of 3/1.5.

c) The conductor size is to meet the minimum recommended dimensions to accommodate the required insulation thickness.

d) Conductors are to comply with IEC 60228 standards for conductivity and material requirements.

e) Conductors are to withstand short-circuit for the minimum duration as specified in IEC60949 or equivalent.

ii) Insulation

a) The insulation material is to be suitable for immersion in seawater.

b) The insulation layer provides electrical insulation, preventing unintended current flow and allowing the cables to operate efficiently. It is designed to be mechanically robust and resistant to temperature variations and aging.

c) Common options for insulation materials include cross-linked polyethylene (XLPE) and ethylene-propylene rubber (EPR). Alternative materials may also be used if they meet the applicable IEC and CIGRE standards.

d) When selecting insulation, the operating temperature and the maximum continuous temperature of the conductor are to be considered to match the thermal requirement of the application.

e) Insulated conductors are to be identified by color or numbering, as specified in the fabricator's written documentation.

f) Minimum insulation thickness is to meet the requirements of IEC standards listed in reference, based on voltage levels as applicable.

iii) Screen/Sheath

a) The screen or sheath provides mechanical protection to the insulation and conductors and shields them from environmental factors, as well as external electromagnetic interference, when the screen is earthed, the induced currents are eliminated.

b) The thickness and number of layers for screen/sheath is to be stated in the fabricator's written specifications.

c) The metal screen or sheath is to be rated to withstand the thermal and mechanical effects of the maximum short circuit current for the specific duration, in accordance with applicable standards.

d) Measures may be taken to achieve longitudinal and radial watertightness in the metal screen/ sheath. When choosing the material for the screen/sheath, special consideration is to be given to the possibility of corrosion, to maintain satisfactory mechanical and electrical performance. Furthermore, mechanical integrity is to be preserved when watertightness is a requirement.

e) Screen/sheath is to meet the relevant IEC or CIGRE standards listed in reference as applicable.

iv) Armor

a) The armor, consisting of round or flat steel wires, copper, thin copper, tapes or other corrosion-resistant metal alloys, provides strength, mechanical protection, and tensile strength during installation.

b) The armor can be single- or double-layer, depending on the required strength defined by the cable fabricator and the installation conditions. For deepwater applications, special attention is to be given to the torsion induced by a single armor layer cable. To prevent this issue, a double armor layer cable (with opposite lay angles) can be used to achieve a torque-balanced cable design.

c) For single-core AC subsea power cables, non-magnetic armor is required to avoid induced current and associated heating and losses in the armor.

d) The armor materials are to be selected with consideration for corrosion resistance to maintain both mechanical and electrical integrity. Bitumen may be applied to the armor layers to protect them from corrosion.

v) Additional Elements

a) Fiber Optic Cables: Integrated within the power cable for communication and monitoring, providing real-time data transmission and system diagnostics.

vi) Outer Protection

a) The outer layer is to provide mechanical protection and retain any anti-corrosion material in position.

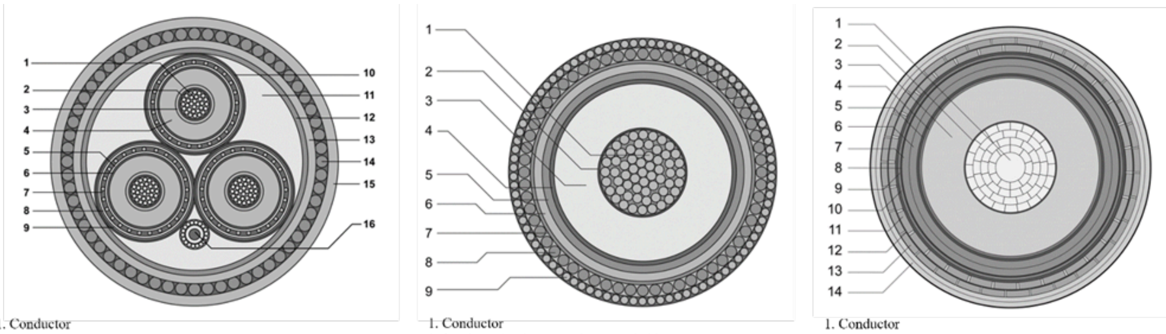
b) Material selection for the outer protection layer is to be based on defined performance criteria, including resistance to cutting, abrasion, deformation, surface fatigue and tensile tearing.

c) The outer protection may consist of a plastic sheath, or multiple layers of yarn coated with bitumen over the armor, depending on the cable design. Where visual identification is required, colored yarns are to be used.

d) The outer layer also provides abrasion protection and contributes to increased bending stiffness of the cable.

The typical design arrangements for subsea power cables are shown in Figure 1:

Figure 1
Typical design of 3-phase AC power cable (left), typical design of single core cables(middle), typical design of MI cables (right)



1. Conductor
2. Semi-conducting tape
3. Conductor screen
4. XLPE insulation
5. Semi-conducting water blocking tape(s)
6. Core non-metallic extruded screen compound
7. Metallic screen
8. Semi-conducting water blocking tape(s)
9. Radial watertightness: laminated tape
10. Polymeric sheath
11. Extruded profile fillers
12. Binding tape(s) with overlap
13. Polymer yarns
14. Armor
15. Outer serving
16. Optical fiber

1. Conductor
2. Semi-conducting tape plus extruded layer
3. XLPE insulation
4. Semi-conducting layer and water blocking tape(s)
5. Metallic sheath
6. Polymer sheath
7. Polymer bedding
8. Armor
9. Outer serving

1. Conductor
2. Conductor screen
3. Insulation
4. Insulation screen
5. Fabric tape
6. Metallic sheath
7. Polymer sheath
8. Bedding tape
9. Transversal reinforcement
10. Bedding tape
11. Armoring
12. Bedding tape
13. Armoring
14. Outer serving

5 Cable selection

Cable selection is determined based on the parameters established through the electrical system analysis outlined in 3/1.11. These parameters include the conductor's cross-sectional area, minimum insulation thickness, conductor characteristics, anticipated voltage drop, and other relevant factors.

5.1 Cable types

Subsea power cables are used to transmit electrical energy across underwater environments and are deployed in applications such as offshore wind farms, oil and gas platforms, and the interconnection between islands or mainland power grids. Cable systems may incorporate fiber optic components to support communication, monitoring and control functions alongside power transmission. Classification of subsea power cables varies globally and is based on factors such as voltage level, insulation type, and mechanical configuration. Refer 1/3 for detailed cable type.

5.3 Cable temperature

The subsea power cable, along with its components and materials, is to be designed for continuous operation within the specified temperature range throughout its design life. The fabricator is to meet the requirement of the maximum operating temperatures in the specification based on relevant standards. Under normal conditions, the cable's operating temperature is not to exceed the maximum limit set by the standard. Considerations include the thermal limits of the cable insulation, environmental conditions, and installation practices.

i) Maximum operating temperature
The maximum continuous operating temperature varies depending on the type of insulation material used. Fabricators are required to specify the rated temperature for each insulation material to achieve thermal and reliable performance.

ii) Short circuit temperature
During short circuits, subsea power cables are designed to withstand higher temperatures for brief periods. The fabricator is to specify these short-duration temperature limits to avoid insulation damage and maintain system integrity.

iii) Thermal resistivity of surrounding materials
The thermal resistivity of seabed materials directly affects cable performance. Sediments with high thermal resistivity tend to retain heat, which can negatively impact cable operation. Therefore, the thermal properties of the surrounding material are to be evaluated during design phase to verify heat dissipation.

iv) Heat dissipation
Adequate burial depth (refer to 3/7.1) and proper spacing between cables are important for efficient heat dissipation. Additionally, using thermally stabilized materials or thermal backfill can enhance heat transfer and improve the cable system's overall performance.

For detailed guidance, refer to the following standards and recommendations:

- IEC 60287
- IEC 60949
- CIGRE TB 623

5.5 Choice of insulating materials

The following are key requirements and considerations when selecting insulation materials:

i) Electrical performance:

a) High dielectric strength to withstand high voltages.

b) High insulation resistance and low permittivity to minimize energy losses. The minimum acceptable DC insulation resistance is 1000MΩ.km@1000V DC.

ii) Thermal performance:

a) Ability to maintain properties at high temperatures, typically up to 90°C for continuous operation and higher for short-circuit events.

b) Good thermal conductivity to efficiently dissipate heat and prevent thermal degradation.

iii) Mechanical strength and flexibility:

a) Flexibility is to accommodate bending and twisting during installation.

b) High tensile strength to endure mechanical stresses during cable laying and operation.

c) Resistance to abrasion to withstand physical wear and tear during installation.

iv) Environmental resistance:

a) Excellent water resistance to prevent moisture ingress during continuous submersion in seawater.

b) Resistance to chemical attacks from seawater and other contaminants.

c) UV resistance to protect exposed sections during installation or operation.

d) Oxidation resistance for long-term performance and protection against material degradation.

v) Treeing resistance:

a) The insulation is designed to resist treeing phenomena, including electrical and water treeing, which are recognized degradation mechanism in medium- and high-voltage cable systems.

Below are typical insulation materials and maximum conductor temperature:

Table 7
Insulation material and maximum conductor temperature

Insulating materials	*Maximum conductor temperature(°C)*	
	Normal operation	*Short-circuit (5 s maximum duration)*
Cross-linked polyethylene (XLPE)	90	250
Ethylene propylene rubber (EPR)*	90	250
Hard grade Ethylene Propylene Rubber (HEPR)	90	250
Mass-impregnated non-draining (MIND) (DC cable)	55-70	N.A.
* Only for cables with rated voltage Um≤245 kV.		

For more details, see the applicable standards and recommendations listed in reference.

5.7 Cable sizing

Sizing subsea power cables involves determining the specifications required to meet the electrical, mechanical, thermal and environmental requirements of a specific project. This process confirms that the cable can transmit the necessary power efficiently under expected operating conditions without risk of damage or performance degradation. There are different methods for sizing cables, the key considerations and calculations involved include the following:

i) Electrical requirements.

- *a)* Power capacity.
- *b)* System voltage.
- *c)* Current capacity.
- *d)* System frequency, if applicable.
- *e)* Harmonics, if applicable.

ii) Conductor.

- *a)* Determine the conductor material (copper or aluminum).
- *b)* Determine the cross-sectional area size of conductor based on the current carrying capacity and acceptable voltage drop. The cross-sectional area is to accommodate mechanical stress during installation and service life.
- *c)* Conductor resistance.

iii) Thermal analysis

- *a)* Determine the maximum allowable operating temperature based on the insulation material, including normal operation and emergency situations.
- *b)* Determine the thermal properties of the cable materials and the surrounding environment.
- *c)* Calculate the thermal resistance between the conductor and metallic screen/sheath, between the metallic screen/sheath and armor, external serving and the surrounding environment.

iv) Calculate current ratings (Ampacity)
In current rating calculation, iterations may be required to calculate the correct current value. Refer to IEC 60287, CIGRE TB 880 or other similar guidelines for relevant calculation methodologies, and consider the following factors:

a) Determine the heat generated by the current in the cable.

b) Calculate the temperature rise in the cable due to the generated heat.

c) Confirm the calculated temperature rise does not exceed the permissible temperature rise.

d) Thermal effects caused by auxiliary equipment and other external factors.

v) Voltage drops and electrical losses.

a) Calculate the voltage drop over the length of the cable and confirm that it is within acceptable limits defined by the approved designs and electrical system analysis.

b) Calculate total electrical losses, including conductor, dielectric, sheath and armor losses.

The selection of cable size is to be confirmed through verification of global dynamic performance, especially where cables are subject to floating offshore wind-induced motions.

7 Cable route

This section outlines the data-collection activities required to support cable route identification, addressing both technical and environmental constraints. The data gathered during this phase are intended to support detailed design and construction activities, minimize the likelihood of rework, and improve project execution efficiency.

Before beginning the cable route design, comprehensive seabed and environmental data are to be available for the entire proposed route, including areas designated for excess cable placement. This section focuses on the development of cable routes and includes:

i) Desktop studies

ii) Cable route surveys

iii) Cable route design

7.1 Desktop study

A cable desktop study constitutes an initial, foundational activity in planning a subsea cable installation project, it establishes the basis for route development and delineates the scope of the subsequent cable route surveys and potential site investigations. The study leverages all available project-site data, identifies information gaps, and delineates areas requiring additional investigation to optimize route selection and support informed engineering decisions.

7.1.1 Objective of desktop study

The objective of a cable desktop study is to:

i) Gather baseline information on potential cable routes.

ii) Recommend suitable route corridors for the cable installation.

iii) Identify preliminary burial requirements and protection strategies for the cable.

iv) Define the scope of the cable route survey and site investigation to be conducted by a survey vessel.

7.1.2 Factor of desktop study

The following aspects are to be considered during the cable desktop study:

i) Location of WTG, substation, and other connecting assets / infrastructure and grid connection points.

ii) Route selection and identification of cable landing points.

iii) Site visits, site condition and constraints, and findings from site visit report.

iv) Applicable code and regulatory requirements.

v) Geophysical and geotechnical surveys required for route evaluation.

vi) Meteorological and oceanographic conditions.

vii) Commercial operations, hazards and restricted areas.

viii) Biological and environmental factors affect the route.

ix) Permitting requirements as applicable.

x) Cable engineering aspects, such as cable type selection.

xi) Risk analysis, including tabulated summaries.

xii) Vessel access and logistics.

xiii) Crossing with existing infrastructure, such as pipelines or cables.

xiv) Route refinement recommendations based on geophysical and geotechnical survey results.

xv) Route selection and optimization.

7.1.3 Report on desktop study

The desktop study report is to provide comprehensive, detailed insights supported by relevant maps, drawings, charts, tables, and photographs to enhance clarity. Key sections of the report are to include:

i) Summary of information collected during the study.

ii) Identified cable landing sites and their suitability.

iii) Preliminary geographic information relevant to the project area.

iv) Initial cable route design, including a preliminary route position list with a geographical coordinate system (e.g. UTM(WGS84)) or an accepted and well-known regional coordinate system.

v) Preliminary cable engineering recommendations, such as cable types, expected quantities, and laying/protection strategies.

vi) Route engineering considerations (e.g., seabed features, slope angles, burial feasibility, regional fault history).

vii) Detailed route description with tables for infrastructure crossings, pipelines, maritime boundaries, and restricted areas.

viii) Seabed and ground conditions analysis.

ix) Restricted areas, exclusion zones, and infrastructure crossings.

x) Distance between parallel cable routes.

xi) Feasible cable protection methods for different segments of the route.

xii) Plans covering geophysical surveys and geotechnical investigations.

xiii) Permitting conditions and associated restrictions.

The following documents provide further guidance on developing a cable route:

- ICPC Recommendation 9.
- ICPC Recommendation 18.

This comprehensive desktop study provides a well-informed foundation for route planning, reducing risks and uncertainties in the subsequent stages of the project.

7.3 Cable route surveys

A cable route survey refines and validates the preliminary route developed during the desktop study by gathering the necessary data to support the engineering, design, installation, and maintenance of the cable throughout its operational life. The cable route survey minimizes uncertainties and reduces environmental impact by providing detailed seabed insights, enabling the most efficient and compliant cable installation. The primary objective of the cable route survey is to:

i) Optimize route selection by gathering data to confirm or adjust the preliminary route.

ii) Support the engineering, design, installation, and maintenance of the cable system.

iii) Collecting and compiling data, such as bathymetry, seabed and sub-seabed features, seabed temperatures, ocean currents, and cable route survey swathe widths.

iv) Identify potential free spans, moving sand dunes, scour protection requirements.

v) Assess seabed characteristics, including depth, gradients, and sediment composition, to determine where the cable can be surface-laid or buried, and to evaluate burial feasibility.

vi) Locate existing infrastructure (e.g., cables, pipelines, or subsea structures) along the cable route survey corridor.

vii) Identify natural hazards such as seamounts, canyons, or turbidity currents, as well as potential risks from volcanic or seismic activity.

viii) Detect sensitive ecosystems (e.g., marine protected areas), hazardous seabed conditions, and cultural heritage sites like shipwrecks.

ix) Plan for specialized cable route surveys if specific hazards, such as unexploded ordnance (UXO), are identified during the desktop study.

x) Minimize environmental impact by conducting cable route survey operations in a manner that avoids or reduces disturbance to marine species in the water column and on the seabed.

The following ICPC recommendations provide further guidance on cable route development and survey operations:

- ICPC Recommendation 2.
- ICPC Recommendation 9.
- ICPC Recommendation 18.

7.5 Cable route design

Designing the route for offshore subsea power cables is a systematic process that integrates desktop study results, cable route surveys, and technical reports to develop an optimized cable layout. The objective is to meet engineering requirements, environmental constraints, and design requirements. The following are the detailed steps and considerations involved in this design process:

i) Geographical information system (GIS).

ii) Location on GIS for WTG, substation and/or other connecting assets / infrastructure and grid connection points.

iii) Cable length at specified location and installation margin requirements for cable length.

iv) Burial method and burial depth.

v) Crossings with existing infrastructure.

vi) Distance between two parallel cables.

vii) Seabed conditions, environmental constraints.

viii) Installation method.

ix) Joint and termination.

Aspects to consider when designing the route layout inside offshore platform:

i) Segregation from low voltage power and control cables to avoid electromagnetic interference and routing conflicts.

ii) The cable support structure is designed to endure both mechanical and electrical short-circuit forces.

iii) Provisions for inspection and maintenance activities, allocate space and access for periodic inspection, testing and maintenance activities.

iv) Consider the location of electrical terminations,

v) Provide adequate corrosion protection.

vi) Follow the fabricator's recommendations for the minimum bending radius of power cables.

Cable route design for offshore subsea power cables requires planning, detailed cable route surveys, and risk management. By considering all relevant factors, engineers can design and implement cable routes that support power transmission while minimizing environmental impact and complying with regulatory requirements.

9 Cable interface

This section specifies the requirements for designing cable interfaces for three different environments: fixed offshore units, floating offshore units, and land-based power systems. Each environment introduces distinct technical challenges, requiring customized design approaches to achieve mechanical integrity, electrical performance, and efficiency operation.

9.1 Interface on fixed offshore unit

The interface design between subsea power cables and fixed offshore units (e.g., platforms, substations) is to address both mechanical and electrical aspects to support long-term, stable operations.

Key consideration:

i) Cable path layout:

a) Avoid proximity to access systems, cathodic protection systems, and hazardous areas.

b) Provide necessary clearance to accommodate installation, maintenance, and lifting activities.

c) Minimize risk of mechanical damage and environmental stress by following suitable routing practices.

ii) Support structure:

a) Design the structure to withstand environmental loads, operational forces, and potential accidental impacts.

b) Incorporate J-tubes or I-tubes with bell-mouths to guide cables from the seabed into the platform with minimal bending stress.

c) Install bend restrictors or stiffeners at critical points to prevent over-bending.

iii) Maintenance:

a) Provide access to cable connections for inspection, testing, and repairs.

b) Implement redundant systems and emergency response measures to maintain continuity of power supply.

Cable accessories and ancillary equipment (as outlined in 3/3.5 and 3/3.7) are to be positioned according to the approved designs.

The following documents provide further guidance on the cable interface on fixed offshore units:

- CIGRE TB 610.
- CIGRE TB 883.

9.3 Interface on floating offshore unit

Dynamic cables are required to accommodate the motion of floating units such as oil and gas floating facilities, floating wind platforms, or other floating offshore units. This interface is designed to manage continuous movement for mechanical and electrical stability.

Key Considerations:

i) Mechanical Design:

a) Cables are designed to withstand dynamic loads and movement caused by waves, wind, and currents.

b) Strain relief mechanisms are to be implemented to maintain minimum bend radii and avoid mechanical stress.

c) Dynamic cable ancillaries, such as buoyancy modules and bend stiffeners, are used to absorb or restrict movements.

d) The mooring system is designed to minimize excessive platform movement that could stress the cables.

e) Cables are to be designed to avoid clashes with adjacent installations.

ii) Anchorage and Protection:

a) Cable armor is anchored to the platform structure or mooring system to manage mechanical loads.

b) Protective conduits and armoring are used to prevent abrasion or impact damage.

iii) Electrical Connections:

a) Connectors, junction boxes, and termination kits designed for marine conditions are installed.

b) Termination kits with integrated strain relief and proven resistance to mechanical stress, vibration, and subsea environmental conditions are used to provide secure connections to the floating unit.

c) Junction boxes or termination chambers with a minimum IP rating in accordance with industry standard, are installed to protect electrical connections against water ingress, corrosion, and mechanical stress in offshore conditions.

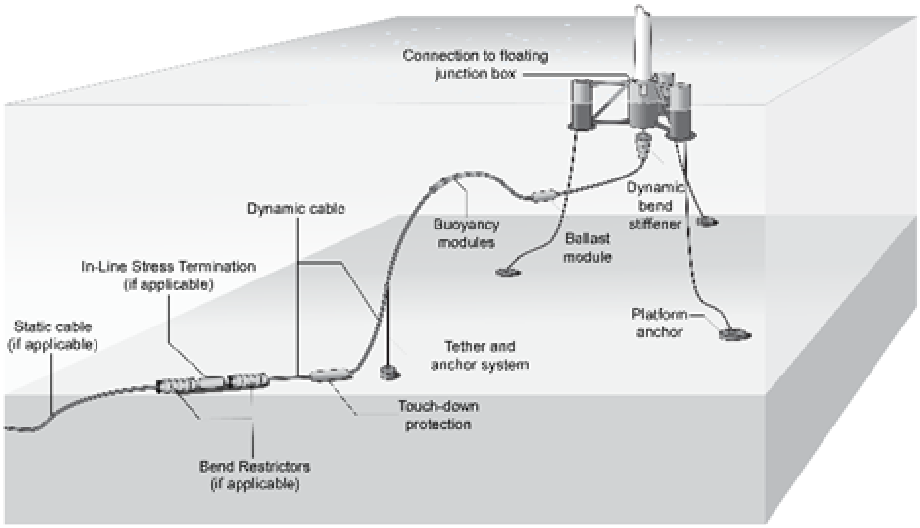
iv) Maintenance:

a) Access to cable connections is provided for inspection, testing, and repairs.

b) Redundant systems and emergency response are implemented to maintain continuity of power supply.

Cable accessories and ancillary equipment are installed according to the actual approved designs and the typical arrangement shown in Figure 2, using mechanical protection components such as J-tubes, buoyancy modules, and clamps to maintain cable integrity, along with bend stiffeners at the floating unit interface.

Figure 2
Typical Dynamic Cable Layout



The following documents provide further guidance on dynamic cable interfaces:

- CIGRE TB 610.
- CIGRE TB 883.
- API 17E.
- API 17L1.
- API 17L2.

9.5 Interface on land-based power system

The sea-to-land transition interface is to provide seamless electrical, thermal, and operational integration with onshore grid or other connecting infrastructure.

Key considerations:

i) Landing site selection:

a) Landing site selection is to be based on the result of desktop study, site surveys, and site investigations.

b) Select geotechnically stable, level coastal area to minimize mechanical stress on the cable and facilitate secure transition joint installation.

c) Minimize the onshore subsea cable length to reduce thermal constraints.

d) Provide necessary space for hauling winches and installation equipment for open-cut or trenching methods.

e) Assess feasibility of pulling the subsea cable to the transition joint bay.

f) Position the transition joint, including connection boxes and fiber optic splice enclosures, as close to the shoreline as practicable to reduce exposure and complexity.

g) Consider soil thermal properties and their influence on cable performance.

h) Determine placement of splice boxes or fiber junction boxes, or both.

i) Proper space for cable introduction, splicing, and future maintenance or fault detection.

ii) Installation Requirements:

a) Provide adequate space for installation tools and equipment.

b) Plan cable routes are to minimize damage risks and provide proper burial depth to protect against external impacts.

c) Shoreline crossing burial options may include:

1) Open-cut trenching.

2) Direct burial.

3) Pre-buried conduit.

4) Horizontal Directional Drilling (HDD).

iii) Mechanical interface:

a) Anchor cable armor to the base of the joint compartment to transfer mechanical loads without compromising cable integrity. If armor supports the cable's weight, terminate at a steel fixture attached to a concrete anchoring block that also serves as the joint base. Alternatively, anchor armor to the flange at the end of the HDD duct, as applicable.

b) Provide adequate length for the shore cable to accommodate remaking the transition joint if a failure occurs during commissioning.

c) Incorporate protective conduits or grooves, where applicable, to shield cables from physical damage such as impacts or abrasions.

d) Confirm that the bending radius is not less than the minimum bend radius during both installation and operation to avoid mechanical stress and potential damage.

e) Design cables and materials to withstand the local environment and operational temperatures.

f) Conductor joints are to possess mechanical properties equivalent to those of the connecting land cables to maintain performance consistency.

iv) Electrical/Optical interface:

a) The sea-to-land transition joint is to connect the offshore subsea cable to the land cable, with joint types selected based on the specific cable types on each side.

b) Optical fiber splicing is to be performed at the transition point.

c) An earthing point is to be provided at the transition joint.

d) Cable accessories, as detailed in 3/3.5, are to be installed at locations determined by operational requirements.

v) Maintenance:

a) Access to cable connections is provided for inspection, testing, and repairs.

b) Redundant systems and emergency response measures are implemented to maintain continuous power supply.

Refer to the following documents for further technical guidance on sea-land transition interfaces.

- CIGRE TB 177.
- CIGRE TB 610.
- CIGRE TB 883.

11 Cable protection

Subsea power cables are to be protected to maintain integrity and functionality through their service life. Protection measures are to address environmental hazards, external impacts, and operational stresses in accordance with project-specific risk assessments.

11.1 General requirements

The general requirements are to apply for cables protections:

i) Protection is required in areas with high anthropogenic hazards, including shipping lanes, fishing zones and regions with significant human activity.

ii) The selected protection method is to be based on document risk analysis considering external threats (anchors, fishing gear, dropped objects, trawling, and construction activities), environmental conditions, technical feasibility, and repair timelines.

iii) Burial depth or alternative protection measures are to be determined through engineering evaluation and are to comply with applicable standards and regulations requirements.

iv) Protection design is to consider soil thermal properties to maintain cable performance within allowable thermal limits.

v) Adequate measures are to be implemented to manage soil cover and account for seabed mobility to confirm long-term mechanical and thermal protection.

11.3 Burial cable protection

Burials are a common protection method for subsea power cables to mitigate potential external hazards. When shielding a cable from external threats, buried within the seabed is typically applied. The burial depth is to be determined based on soil conditions and specific risk factors affecting the cable. In areas with sand or soft soil, the cable is to be buried at least 0.5 meters to protect against fishing gear. However, the required depth may vary based on factors such as vessel activity, fishing operations, and local seabed conditions. If there is a risk of anchor drops, increased burial depth may be required. These factors are to be evaluated and addressed during design phase.

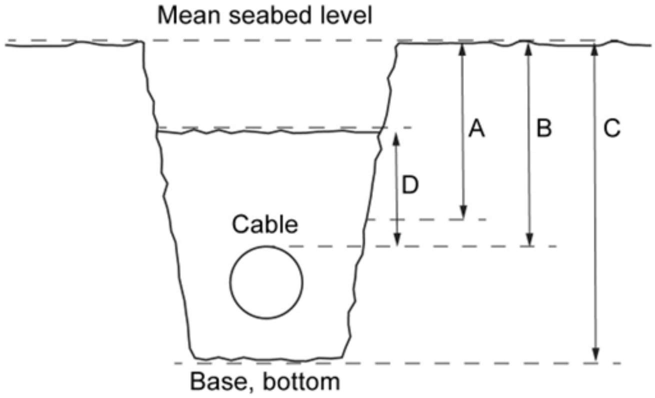
Burial depth can influence the cable's rated current. Therefore, risk assessment is to be conducted to evaluate potential threats and determine the most suitable protection method, risk assessment approaches may include qualitative, semi-quantitative, quantitative, and probabilistic approaches.

Cable Burial Risk Assessment (CBRA) is a widely used probabilistic method for evaluating risks to subsea power cables. It supports determination of effective protective measures, including burial depth.

Upon completion of risk assessment, a recommended mitigation or avoidance strategy is proposed along the cable route. If burial is selected as the protection method, determination of optimal burial depth is to follow a technical process that balances protection requirements with identified risks. The final burial depth will vary according to site-specific conditions and risk levels. For methodology, refer to CIGRE TB 883 and Carbon Trust, CTC835.

Once burial depth is established, the cable burial design is to define the trench geometry along the entire route, including key parameters, burial depth and cover depth, as illustrated in Figure 3 below:

Figure 3
Cable Burial Parameters



A Recommended minimum depth of lowering
B Target depth of lowering
C Target trench depth
D Depth of cover

The selection of burial techniques and tools will be based on site conditions, cable characteristics, burial depth requirements and burial equipment.

11.5 Non-burial cable protection

Where cable burial is not feasible or permitted, external protection systems can be used to safeguard the cable. Compared to buried cable protection, non-burial protection may be necessary in the following circumstances, where burial protection is impractical, uneconomical, or forbidden by regulation:

i) Sea/land joint area.

ii) Interface between the cable and offshore units.

iii) Infrastructure crossing area.

iv) Locations where the seabed is too hard for ploughing or jetting and a rock cutting system is not a viable option.

v) Regions where trenching is impractical or uneconomical.

vi) Areas with highly uneven terrain, such as areas with boulders, are unsuitable for burial tools.

vii) Deep-water areas (greater than 200 meters), where the risk of anchor damage is low, protection for subsea power cables may be deemed unnecessary depending on fishing activity and other risk factors.

For offshore subsea power cables, several non-burial protection methods are available to mitigate damage from environmental factors, human activities, and marine life. The following sections outline typical non-buried protection approaches and their applicability to subsea power cables:

11.5.1 Rock placement

Rock placement is a non-burial protection method for subsea power cables in locations where burial is not feasible, such as at crossings with third-party assets. This method typically involves placing multiple layers of rock with varying sizes. The design of rock placement is to consider site-specific conditions and the intended applications. For detailed guidance, refer to CIRIA C683.

Minimum design considerations include:

i) Site conditions, rock size, berm side slope, and height.

ii) Over-trawl ability and protection against dragging anchors.

iii) Impact energy during installation.

iv) Adaptation to seabed displacements.

v) Rock materials selection.

vi) Logistic factors.

vii) The stability of both the rock placement and the cables.

The impact of energy transmitted to the seabed, cable, and any attached elements depends on rock size, weight, and placement configuration. To verify the cable system's resilience, an impact test in accordance with CIGRE TB 623 may be required.

11.5.2 Mattress coverings

Concrete mattresses consist of interlinked concrete blocks of varying dimensions and thicknesses, offering flexible protection that conforms to seabed contours and protected assets. Concrete bags (single-block units) provide a simpler, lower level of protection suitable for protecting individual cables and generally less robust than mattresses. Both mattress and bag systems can be used for trenched and non-buried installations and for cable crossings, depending on site conditions and protection requirements.

Minimum design considerations include:

i) Site conditions, including mattress size and weight.

ii) Over-trawl resistance and external impact protection against dragging anchors, or other underwater activities.

iii) Adaptation to scouring to maintain cable stability.

iv) Crush and load resistance for durability under applied loads.

v) Stability of mattresses and cables.

11.5.3 Articulated pipe cable protectors

The installation of articulated pipe cable protectors provides enhanced protection for cables in a range of challenging environments, including:

i) High-energy wave zones.

ii) High-current areas.

iii) Sediment mobility zones.

iv) Hard seabed crossings.

v) Riser protection areas.

These protectors are to be designed to address specific site conditions and application requirements. Key design considerations include:

i) Prevent bending below the cable's minimum bending radius or incorporating bend stiffeners.

ii) Enhance stability by adding mass to the system.

iii) Protect cables from dropped objects and other accidental impacts.

iv) Use corrosion-resistant or corrosion-free materials, such as cast iron or polymer composites.

v) Account for thermal dissipation to avoid overheating.

vi) Maintain a smooth, protrusion-free outer surface to reduce risks during handling and operation.

vii) The articulated pipe protector can be made from metallic material (typically cast iron) or plastic materials (typically PU).

SECTION 4

Fabrication and Testing

1 General

The cable fabricator is responsible for producing subsea power cables, associated accessories. The fabrication process includes all activities up to the point which the products are ready for delivery. This section outlines the requirements for the fabrication process, together with the required testing and the documentation to be prepared and agreed upon by the stakeholders.

3 Fabrication process qualification

Fabricators involved in the production of cables, components, and associated/interface products are expected to comply with defined process qualification requirements. These activities are intended to establish effective control over quality, testing, and documentation throughout the fabrication process. The fabricator is responsible for conducting these activities, maintaining relevant records, and coordinating any purchaser or third-party witness participation as specified by contract. The following outlines the minimum requirements within the fabricator-scope for process qualification.

i) Quality management and implementation.

a) Stakeholders involved in the fabricating of cables, components, and associated/interface products are to maintain a documented and implemented quality management system (QMS) that complies with ISO 9001 or an equivalent standard, certified by a recognized certification body. The QMS scope is to reflect the organization's size, operational processes, complexity, and the competence of its personnel.

b) All fabrication, assembly, testing and repair work is to be performed in accordance with written procedures under the fabricator's control and approved by the purchaser where contractually required.

c) Prior to work starts, the fabricator is to prepare and submit an Inspection and Test Plan (ITP) or equivalent for agreement with the purchaser. The ITP is to define planning, process control, hold points, witness points, test procedures, acceptance criteria and reporting requirements. Where acceptance criteria are not specified by applicable standards or purchaser documents, the fabricator is to propose criteria for purchaser review and agreement.

d) The fabricator is responsible for supervision of all activities, including repairs and remedial actions, and for verifying personnel are competent and qualified for assigned tasks.

ii) Inspections, witnessing and third-party coordination
The fabricator is responsible for planning and conducting internal inspections and tests in accordance with the approved ITP and QMS. The fabricator is also expected to facilitate witnessing and verification activities by the purchasers and any agreed third party or owner representatives, as specified in the contract.

Typical inspection and witnessing activities are to be carried out at the fabricator’s facility in accordance with ITP, and include, but are not limited to, the following:

a) Verification of material specifications during procurement.

b) Review of documentation and controls to verify and maintain material traceability.

c) Verification of dimensional and functional checks of finished cables, components and parts.

d) Review and control of fabrication procedures and personnel qualifications.

e) Inspection of preparatory work and process setup.

f) Verification that fabrication processes comply with approved specifications and procedures.

g) Witnessing testing hold points activities (routine and acceptance tests) per ITP.

h) Inspection and documentation of repairs and rework.

i) Verification of welding requirements for joints, terminations, connectors, etc., and associated qualification records.

j) Verification of NDT written procedures, operator’s qualification and NDT plans.

k) Witnessing of hydrostatics and other pressure tests per ITP.

l) Examination and verification of calibration for testing, measuring, and recording equipment important to fabrication and tests.

m) Witnessing FAT when required per ITP.

If the fabricator identifies a high rate of non-conformities during execution or quality assurance, the fabricator is to initiate a root cause analysis and implement remedial actions. Remedial actions may include repairs, re-qualification of personnel, design or material changes, process adjustments, and re-inspection or re-testing as necessary. All actions and results are to be recorded in accordance with the QMS and contract requirements.

iii) Documentation and records

The fabricator is responsible for making required documentation and records are readily available at the fabrication site and retained in accordance with the QMS and contractual retention periods, Minimum documentation includes:

a) QMS documentation: quality manual, detailed quality assurance plans, and records demonstrating implementation and compliance.

b) General arrangement drawing, and any applicable engineering drawings.

c) Certification and traceability records, such as material certificates, equipment calibration certificates, personnel qualification records, process documentation, and test reports.

d) Inspection and test records documenting activities, results, hold/witness point outcomes and acceptance evidence.

e) Technical specifications and applicable engineering documentation detailing design and performance requirements.

f) Records of non-conformities and remedial/corrective action records, including disposition, rework and verification of effectiveness.

g) The fabricator is to provide copies of requested records to the purchaser or an agreed third party, in accordance with the ITP and contract reporting requirements.

5 Cable fabrication

Cable fabricators may produce stock cables based on their own subsea power cable specifications and the approved designs, provided these cables comply with industry testing and qualification standards or the requirements set out in this document. For specific offshore projects that use either the fabricator’s existing stock cables or custom subsea power cables, all design parameters, material selection, testing requirements, cable storage (see Appendix 2), and applicable technical standards are to be mutually agreed upon by the fabricator and the purchaser.

7 Cable testing

This section introduces the types of tests that are to be performed on subsea power cables and their components during the fabrication and lifecycle. These tests demonstrate compliance with technical standards and confirm performance under design conditions and detect potential defects early to prevent failures.

7.1 General

The testing program for subsea power cables and their accessories is to follow the guideline set by IEC standards, CIGRE recommendations and API. It typically includes development testing, pre-qualification testing, type testing, routine testing, sample testing, extension of qualification testing, and post-installation testing. These tests are designed to achieve the required standards and maintain structural integrity, functional consistency, and operational effectiveness throughout the product lifecycle.

The subsea power cable testing procedure, together with acceptance criteria, test temperature range, AC voltage frequency and waveform, test voltages relative to the rated voltage and reference standards, are specified in the table below:

Table 1
Tests of Subsea Power Cable System

Tests	*Test Type*	*Subcategory*	*Reference*
Type test	Mechanical tests	AC	IEC 63026 (6kV-60kV), CIGRE TB 490 (30kV-500kV), CIGRE TB 623 (Above 30kV), CIGRE TB 722 (6 kV-60kV).
		DC	CIGRE TB 496 (up to 500kV), CIGRE TB 623 (Above 30kV).
		Dynamic Cable	IEC 63026 (6kV-60kV), API 17E (1kV-30kV), CIGRE TB 862 (Above 30kV), CIGRE TB 722 (6 kV-60kV).
	Electrical tests	AC	IEC 60502-2 (1kV-30kV), IEC 60840 (30kV-150kV), IEC 62067 (150kV-500kV), IEC 63026 (6kV-60kV). CIGRE TB 490 (30kV-500kV), CIGRE TB 722 (6 kV-60kV).
		DC	CIGRE TB 496 (up to 500kV), CIGRE TB 852 (up to 800kV), CIGRE Electra 189 (up to 800kV).
1. Routine test 2. Sample test 3. Prequalification tests 4. Extension of qualification tests 5. Electrical tests after installation	NA	AC	IEC 60502-2(1kV-30kV), IEC 60840(30kV-150kV), IEC 62067(150kV-500kV), IEC 63026 (6kV-60kV), CIGRE TB 490 (30kV-500kV), CIGRE TB 722 (6 kV-60kV).
	NA	DC	CIGRE TB 496 (up to 500kV), CIGRE TB 852 (up to 800kV), CIGRE Electra 189 (up to 800kV).
Optical fiber tests *	NA	NA	ITU-TG 976, IEC 60793, IEC 60794, CIGRE TB 722 (6 kV-60kV).

Note:
* Optical fiber tests are to be performed during development, fabrication, installation, commissioning, and operation and maintenance phases.

7.3 Type tests and range of type approval

The purpose of type testing for cable systems is to verify that their performance meets the intended application and comply with the design performance criteria. These tests include mechanical, electrical, material, and water-penetration tests (both longitudinal and radial) on complete cable systems, as well as applicable non-electrical tests on individual components, as outlined in Table 1. Once successfully completed, type tests do not need to be repeated unless there are changes in materials, fabrication processes, design, or electrical stress levels that could affect performance.

If type tests have been successfully carried out on one or more cable systems with defined cross-, rated voltage, materials, design, and construction process, the type approval may be extended to other cable systems within the same scope. Conditions for extending this approval to other variations are provided in the relevant IEC standards and CIGRE guidelines referenced in 4/7.1.

7.3.1 Type tests on AC cable system

The test method, acceptance criteria, preconditioning, and test sequence for complete cables and accessories may vary depending on the specific type of cable and cable system. Detailed information is to refer to relevant IEC and CIGRE guidelines specified in 4/7.1. Minimum type tests with an AC cable system are to include the following:

Table 2
Potential type tests on AC cable systems

Type Tests	*Description*
Mechanical tests	Coiling test if applicable
	Tensile bending test
	Tensile test
	Water penetration tests
	Non-electrical tests
	Full-scale fatigue tests for dynamic cables
Electrical tests	Partial discharge test at ambient temperature.
	Tan(δ) measurement test.
	Heating cycle voltage test.
	Partial discharge tests
	Switching impulse voltage test
	Lightning impulse voltage test followed by a power frequency voltage test
	Visual examination of the cable system with cable and accessories on completion of the above tests.
	The resistivity of the cable semi-conducting screens is to be measured on a separate sample.

7.3.2 Type tests on DC cable system

All components of the DC cable system, including the cable itself and its associated accessories, are to undergo type testing. The testing method, acceptance criteria, preconditioning and sequence of tests for the complete cable system and its accessories may vary depending on the specific type of cable and cable system involved. For details regarding the tests for DC cables and accessories, refer to the relevant IEC standards and CIGRE guidelines outlined in 4/7.1.

The minimum type tests for a DC cable system are to include the following:

Table 3
Potential type tests on DC cable systems

Type Tests	*Description*
Mechanical tests	Coiling test if applicable
	Tensile bending test
	Tensile test
	Non-electrical tests
	Water penetration tests
Electrical tests	Loading cycle tests
	Polarity reversal tests
	Superimposed impulse voltage tests
	Visual examination of the cable system with cable and accessories on completion of the above tests.
	The resistivity of the cable semi-conducting screens is to be measured on a separate sample.
Return cable tests	AC voltage test
	Lightning impulse withstand test
	Cable design with integrated return cable tests

Upon completion of type testing, evidence of the tests may include: a type test certificate signed by a representative of a qualified witnessing body; a test report issued by the fabricator and signed by a qualified official; or a type test certificate issued by an independent testing laboratory.

7.5 Routine tests

Routine testing is performed to demonstrate the integrity of fabricated cables and fabricated lengths and to verify that the product meets design and fabrication specifications within specified tolerances.

Minimum routine testing includes:

Table 4
Potential routine tests on cable systems

Test Category	*Tests Included*
Tests on fabricated lengths of cable	Partial discharge test, high voltage test, electrical test on over sheath (if applicable, per IEC60229), measurement of electrical resistance of conductors (if applicable), TDR measurement for DC cable (if applicable)
Tests on factory joints	PD measurement (if applicable), X-ray inspection, AC voltage test (if applicable), DC test for DC factory joints
Test on complete delivery length of cable	High voltage test, partial discharge test
Tests on repair joint	Refer to IEC standard or CIGRE guidelines specified in 4/7.1
Tests on termination	Refer to IEC standard or CIGRE guidelines specified in 4/7.1
Tests on return cables or conductors for DC cables	AC or DC test (if applicable)
Factory acceptance test	Refer to 4/11

Routine tests do not apply to heat or cold shrink accessories or to accessories taped and /or molded on site.

7.7 Sample tests

Cables and certain types of cable accessories are to carry out sample testing.

Sample tests are to be specified according to IEC standards and CIGRE guidelines referenced in 4/7.1, including:

Table 5
Potential sample tests on cable systems

Category	*Details*
Conductor, insulation, sheath examination	Examination of conductor, insulation, sheath, dimensions, and diameters
Hot set test	Hot set test for insulations
Bending test	Bending test (if applicable)
Water penetration test	Water penetration test (if applicable)
Electrical testing	Impulse voltage, resistance of conductors and metal screen/sheath, frequency, and capacitance
Thickness measurement	Measurement of thickness of insulation, non-metal sheaths, and metal sheaths (if applicable)
Density measurement	Measurement of density of insulation (if applicable)
Repetition of tests	Repetition of tests (if applicable)
Tests on accessories	Tests on components and complete accessories, such as joints and terminations

7.9 Pre-qualification test

The prequalification (PQ) test is intended to assess the long-term electrical, thermal and mechanical performance of the complete cable system (see 1/13 for definition of cable systems) under realistic conditions. It is required only once unless significant changes are made to materials, processes, design, or electrical stress levels. If modifications are made but deemed non-substantial, the fabricators are to provide a detailed justification supported by test evidence.

Cable fabricators who pass the PQ test are authorized to supply the same family of cable systems with equal or lower voltage ratings, provided that the nominal electrical stress of the insulation screen in the new system does not exceed that of the previously tested cable.

Detailed requirements for PQ testing are specified in IEC standard and CIGRE guideline referenced in 4/7.1 and CIGRE TB 303.

7.11 Extension of pre-qualification test

If a pre-qualified cable system (see 1/13 for definition of cable systems) is modified by replacing a cable or accessory with another that has already been prequalified in a system with equal or higher nominal electrical stress at the insulation screen, the existing prequalification may be extended. This extension is granted if all requirements of the extension of prequalification (EQ) test are met. The EQ Test is intended to assess the impact of these changes without requiring a full PQ test, thereby making the qualification process more efficient. The EQ test can be carried out in a laboratory and does not necessarily need to simulate actual installation conditions.

Detailed requirements for EQ testing are specified in IEC standard and CIGRE guidelines referenced in 4/7.1 and in CIGRE TB303.

7.13 Post-installation test

After the cable system is installed, tests are to be carried out on the new installation. For details, see the commissioning and testing 6/3.

7.15 Development tests

Development tests are a series of evaluations performed on new cables or accessories to assess and validate their designs, materials, components, production processes, installation conditions, or long-term performance. The fabricator determines the scope and specifics of these tests. If a development test is required as part of project, it is to be mutually agreed upon by both the fabricator and the purchaser. Detailed testing procedures are outlined in IEC standard, CIGRE TB 490, CIGRE TB 496, CIGRE TB 610 and CIGRE TB 303.

9 Optical fiber testing

Optical fiber testing is to be conducted to verify that the fibers meet the system's functional performance, and service-lift requirements throughout the development, fabrication, installation, commissioning, and maintenance phases. Detailed testing methods and procedures are outlined in 4/7.1.

11 Factory acceptance testing

Factory Acceptance Testing (FAT) is an important step in verifying the compliance and integrity of subsea power cables before they are shipped to the installation site. FAT is to allow a third-party inspector or customer representative to witness the testing to verify that the testing protocols are followed and that results meet the acceptance criteria.

Key FAT requirements for subsea power cables include:

i) Visual inspection.

ii) Dimensional verification.

iii) Relevant FAT tests as defined by the IEC standard and CIGRE guideline referenced in 4/7.1.

iv) Documentation of test procedures, results, and witness records.

v) Final inspection and packing.

SECTION 5
Transportation and Installation

1 General

The transportation and installation (T&I) of subsea power cables is a key operation. The process requires detailed planning, specialized equipment, and compliance with specific technical and procedural requirements. The cable fabricator is to provide all relevant mechanical parameters and the acceptable specifications for equipment used to handle the cable.

Transportation and installation procedures are to be developed by T&I contractors based on the results of installation analyses to meet the specified approved designs. The procedures are to cover both normal and emergency operations, and detail each transportation, installation, inspection and testing step, they are to also incorporate findings from a risk management study performed for T&I, which is to specify the control parameters and allowable variations during transportation and installation.

Additionally, the T&I procedures are to reflect the limits established during design stage (for example, wave height and sea-state limits). Procedures are to require that all activities stay within these design limitations and that any potential damage discovered during transportation and installation be promptly identified and addressed, considering personnel protection and the capacity of installation equipment.

In accordance with the statement of methods outlined in the approved designs, the procedure is to include the following elements:

i) A description of the materials, tools and equipment to be used, operational constraints and proposed working methods.

ii) Identification and management of interfaces with works carried out by other parties.

iii) An assessment of potential environmental impacts and proposed mitigation measures.

iv) A comprehensive evaluation of potential hazards, including identification, risk analysis, and proposed mitigation strategies.

Procedures for each individual element and phase of the work are to be clearly defined, detailing the necessary steps for successful installation. These procedures are to consider all relevant engineering requirements and the expected weather conditions. Additionally, all design criteria and assumptions related to transportation and installations, as set out on the design basis and functional requirement, is to be explicitly stated.

1.1 Planning

The transportation and installation of the cable system are to be planned with attention to detail to minimize risks.

All relevant findings from preliminary studies and risk assessments, conducted in accordance with the approved designs outlined in Section 3, are to be integrated into each stage of the process. These studies form the foundation for installation, engineering and planning.

Aspects such as cable route selection, environmental conditions, seabed characteristics, potential hazards, and procedural requirements, are to be evaluated and addressed during the early stages of design. This evaluation enables early identification of potential risks and supports the development of effective mitigation measures and contingency plans.

The planning process is to cover all aspects of cable handling, including storage, testing, transportation to the installation site, cable laying and jointing, and protection on or beneath the seabed. All key steps are to be clearly identified and analyzed to support the development of detailed procedures or manuals.

The suggested planning is to cover, but is not limited, the following activities:

i) Deployment of vessels and cable handling system.

ii) Inspection and testing plans (ITPs) for transportation and installation phases.

iii) Package analysis for transportation and installation (see 2/5.3.2/xiii).

iv) Cable system storage requirements (see Appendix 2).

v) Cable and accessory loading and securing.

vi) Cable load-out facilities and procedures.

vii) Route preparation activities.

viii) Cable landings at the beach and pull-in operations, including:

- *a)* Pulling the cable into the beach manhole or through HDD ducts.
- *b)* De-burial of duct ends.
- *c)* Cleaning of duct.
- *d)* Removal of seals.
- *e)* Pull-in to platforms.
- *f)* Hang-off.
- *g)* Cable sealing and routing on deck.

ix) Cable installation, including:

- *a)* Control of cable slack during installation
- *b)* Cable marking and residual tension logging.
- *c)* Monitoring and verification strategies.

x) Touchdown monitoring and verification of lay parameters.

xi) Electrical testing before and after installation.

xii) Cable jointing and deployment of joints.

xiii) Cable protection measures, including:

- *a)* Simultaneous or post-lay burial.
- *b)* Mechanical protection as per the scope of work.

xiv) Diving operations, as applicable.

xv) Management of unforeseen seabed obstructions, such as:

a) Chemical waste, ordnance, debris or hazardous items.

b) Archaeological findings.

xvi) Design and execution of subsea infrastructure crossings.

xvii) Vessel traffic coordination and liaison with maritime authorities.

xviii) Weather and environmental evaluation.

xix) Support ship operations.

xx) Crew transfer between vessels and offshore assets.

xxi) Installation and withdrawal of equipment to/from offshore assets.

xxii) Cable pull-in to offshore assets or landfall, including temporary hang-off.

xxiii) Permanent hang-off system design and deployment.

xxiv) Pre-lay, post-burial and post-installation cable surveys, as required.

xxv) Measurement and monitoring techniques, including:

a) Depth of burial.

b) Data logging for specific installation parameters.

The planning documentation is to describe each activity in detail to allow comprehensive assessment of the proposed engineering solutions, tools, equipment, measuring techniques, manpower, vessels, and other resources.

1.3 Operation limitations

Operational limitations are to be clearly defined based on the capabilities of the selected vessel, the specific requirements of the planned installation, the expected weather conditions, and the availability of contingency measures.

Operational limits are to be established with consideration of the following factors:

i) Weather conditions.

ii) Vessel capabilities (e.g., station-keeping ability).

iii) Duration of operations and available time windows.

iv) Cable handling and installation processes.

v) Seabed conditions.

vi) Environmental and ecological constraints.

vii) Equipment and technological constraints.

viii) Operational coordination and communication.

ix) Installation techniques.

x) Risk analysis.

xi) Contingency planning and emergency procedures.

These operational limits are to be objective and measurable, and enforceable to confirm that activities are completed within defined thresholds. Achieving this may include:

i) Completion of the operation.

ii) Reversal of the operation.

iii) Termination of the operation.

iv) Placing the operation on standby until conditions improve.

3 Vessel and tools

The selection of a cable laying vessel depends on several factors, including the cable design, cable length, water depth, operational area, and environmental conditions. Options range from cable barges to ships. In general, the chosen vessel is to be equipped with the following features:

i) Adequate storage space for cables, considering the cable's storage and installation minimum bending radii.

ii) Storage space environmental controls that meet the cable fabricator's requirements.

iii) Adequate straight-line length or deck space to avoid handling difficulties, such as pig-tailing, bird-caging or armor lock-up.

iv) Cable-coiling facilities and cable-tensioning machines.

v) Maneuverability to provide station-keeping and accurate placement of the cable along the selected route.

vi) Tension control equipment, tension measuring instruments, and a cable deployment system.

vii) Deck facilities for both cable installation and recovery/repair operations.

viii) Workshop facilities for equipment maintenance and cable jointing.

ix) Control rooms for managing equipment and data logging systems.

x) A positioning system capable of maintaining the required position/heading accuracy for the planned operation and environmental conditions.

xi) Navigation and propulsion systems are adequate to maintain vessel position.

xii) Anchoring equipment.

xiii) Suitable draft and weight capacity for the intended operations.

xiv) Applicable trading certificates.

If a dynamic positioning (DP) vessel is selected as the cable-laying or support vessel, it is to be designed, equipped, and operated in accordance with the relevant classification society requirements and IMO MSC.1/Circ. 1580 guidelines.

Tools for subsea cable operations can be broadly categorized into cable handling tools, cable burial tools, and subsea positioning/monitoring tools. Tool selection depends on cable type, seabed conditions, and installation techniques. A more detailed breakdown follows:

i) Cable handling tools:
Cable handling tools are required in cable storage, transportation, installation, and recovery. All cable handling equipment is expected to comply with the critical cable handling parameters (CCHP) of the cable and applicable statutory requirements. For example, during cable installation, the cable lay equipment is required to maintain the cable's top tension on the vessel or barge. In addition, valid certificates for relevant equipment are to be available on board for review.
Typical cable handling tools include:

a) Cranes.

b) Cable monitoring tools.

c) Tensioners and relevant technical parameters.

d) Drum cable engines/capstans.

e) Cable turntables or reels.

f) Cable tank.

g) Cable engines/traction winches.

h) Cable chutes/sheaves.

i) Cable baskets.

j) Rollers and quadrants.

k) A-frames and davits.

l) Cable jointing and splicing equipment.

m) Tension monitoring system.

ii) Cable burial tools:
These tools are utilized to embed the cable beneath the seabed to protect it from external damage, such as anchor strikes or fishing activities. Burial depth and method depend on seabed conditions, cable type, and cable routing requirements. Common tools include:

a) Ploughs.

b) Jet trenchers.

c) Mechanical trenchers.

d) Remotely operated vehicles (ROVs) with burial capabilities.

iii) Subsea positioning and survey tools:

a) The towed cable survey unit (or equivalent) is typically equipped with a subsea positioning tool (e.g., an ultra-short baseline (USBL) system) to monitor the cable position during installation.

For more details on the vessel and tools, refer to Section 3.8 of CIGRE TB 883.

5 Pre-lay survey and site preparation

Before site preparation, a pre-lay survey of the cable route is to be conducted if there have been significant changes in the marine environment since the initial seabed survey and site investigations or if substantial alterations to the seabed conditions are expected. Marine factors, such as storms, currents, or human activities, can alter the seabed, introducing new obstacles or risks. A new seabed survey and site investigations help identify these changes, confirming the cable route remains viable and suitable for continued operation under the defined design conditions. It also allows adjustments to burial depth, protection measures, and installation techniques to account for current conditions, minimizing potential issues during installation.

5.1 Pre-lay survey

A pre-lay survey is to be conducted prior to commencing cable installation. This survey is to be performed along the proposed route and across the designated cable corridor to confirm the seabed conditions are suitable for installation.

The pre-lay survey is an important step in achieving successful deployment and the long-term integrity. It involves a detailed assessment of the planned cable route on the seabed using suitable technologies and methodologies.

The pre-lay survey is to aim to:

i) Identify any debris or obstacles on the seabed and determine any required clearance operations to confirm a clear and unobstructed path for installation.

ii) Confirm that the seabed conditions, as assessed during the initial cable route survey, remain unchanged and that no new obstacles or hazards have emerged.

iii) Optimize the planned cable route, if necessary, based on pre-lay survey data to avoid problematic areas and facilitate a smoother, more efficient installation.

5.3 Route preparation

The following activities are to be undertaken during cable route preparation to support subsea cable installation:

i) Assessment of seabed and shore-end conditions: Evaluate site-specific conditions such as unstable slopes, sand waves, deep valleys, erosion to prevent exceeding the design limits of the cable system.

ii) Cable path selection and clearance: Determine the optimal cable path based on pre-lay survey data, avoid high-risk areas and remove debris, including rocks, fishing gear, and other anthropogenic objects, using suitable equipment. Where applicable, remove unexploded ordnance (UXO) in accordance with relevant protocols.

iii) Seabed preparation: Prepare the seabed in hard or uneven areas to establish a stable and continuous cable path.

iv) Crossing preparation: Prepare for pipeline and cable crossings in accordance with engineering design and applicable standards.

v) Seabed verification: Confirm that the seabed is free from newly introduced hazards and is suitable for cable installation.

vi) Risk assessment: As applicable, conduct a risk assessment and identify and mitigate potential risks associated with route preparation.

vii) Activity logging: Record all route preparation activities and site observations in a structured format.

viii) Documentation: Maintain documentation of all actions to support compliance and future reference.

7 Cable load-out

Cable load-out is the process of transferring subsea power cables between locations. Clear responsibilities for cable management at each stage are to be established, and the specific point at which responsibility transfers between parties is to be mutually agreed upon before operations commence.

7.1 Load-out facilities

Load facilities are to be prepared in accordance with the requirements outlined in the transportation and installation plan (see 5/1.1) and the approved designs prior to commencing load-out activities. At a minimum, the following aspects are to be addressed:

i) Onshore storage, the cable system is to be stored in accordance with Appendix 2.

ii) Onshore cable handing systems:

- *a)* System type control and communication procedures are to be defined for all personnel involved.
- *b)* The pay-out speed range is to be defined as an operational requirement based on the fabricator's recommendation.
- *c)* The interface between the storage facility and the vessel cable handling system is to be clearly defined and agreed by both parties.
- *d)* Handling limitation is to be established based on fabricator's recommendation (e.g., weights, minimum bend radius, crush load limits), including any accessories/ancillary equipment constraints.
- *e)* Crane and lifting facilities, lifting equipment certification is to be verified.

iii) Vessel and equipment compatibility *a)* The installation vessel is to be suitable for carrying the cable, considering deck space, load capacity, stability, positioning capabilities.

b) Constraints related to the vessel's draft and other dimensions are to be clearly defined.

c) The vessel is to meet mooring and maneuverability requirements.

d) Crane specifications are to be verified for handling the cable and associated equipment.

7.3 Load-out planning

A load-out plan is to be developed including all steps and interfaces of the process. The plan is to describe the proposed operations, identify all necessary equipment, and detail the methods and tools for handling terminations, joints, ancillary components, and similar items. Load-out activities are to be scheduled during favorable weather conditions to minimize risks of delays and potential cable damage. The plan is to define clear communication protocols and assign responsibilities for each phase and load-out process. Additionally, the plan is to specify the agreed handover point from the fabricator to the installer or purchaser.

7.5 Pre/post load-out tests

Pre-load-out tests are to be conducted when the subsea power cable system is to be transported from the fabricator's site to another location or stored for an extended period. These tests are to be completed prior to the load-out operation. Similarly, post-load-out tests are to be carried out immediately after load-out. The following minimum tests are required for both pre- and post-load-out procedures.

i) Visual inspection to verify that no damage has occurred to the outer sheath or armoring.

ii) DC-conductor resistance test for all cores, the measured resistance of each conductor, corrected to 20°C, is to not exceed the value specified in IEC 60228 by more than 2%.

iii) DC-resistance test for each metallic sheath or screen.

iv) Insulation resistance test.

v) Time-domain reflectometry (TDR) test.

vi) Optical time domain reflectometer (OTDR) test, where applicable.

7.7 Load-out operation

The load-out operation is to follow the approved load-out plan. All personnel involved are expected to understand the plan, including communication procedures, the operation schedule, and the applicable precautions. Additionally, all onshore and onboard equipment intended for use during the load-out operation is to be verified for proper calibration and functionality. Functional testing and calibration records are to be reviewed and confirmed prior to commencing the operation. The following outlines the minimum requirement for load-out operation:

i) The load-out operation is to confirm that no unacceptable levels of twist, bending, or tension are introduced to the cable. All mechanical loads applied during the process are required to remain within the allowable limits specified by the fabricator.

ii) When transferring cables across spans, provide proper support to maintain the minimum bend radius. Suitable supports (rollers, caterpillars, bend shoes, sheaves, chutes, etc.) may be employed. Continuously monitor the catenary and adjust the loading speed as necessary.

iii) The cable is to be lifted using methods (e.g., pulling heads) designed according to the cable fabricator's specification. All related lifting equipment is to undergo independent verification.

Monitoring is to be carried out during all load-out operations to prevent damage to cables, accessories, or ancillary equipment, the loaded cable length is to be documented. Detailed records of all test results, inspection reports, and equipment calibration certificates are to be maintained.

9 Cable transport

During transportation of the subsea cable system, the following minimum requirements are to be met:

i) The onboard cable storage system is to have adequate strength to support the weight of the cable under all conditions encountered during transport.

ii) Evaluate the load-bearing capacity of the cable handling system to support both the static cable weight and dynamic loads caused by vessel motions, confirming that these loads do not exceed the equipment's capacity.

iii) Inspect securing mechanisms (straps, clamps, or lashings, etc.) to confirm they are suitable for the intended purpose and capable of maintaining stability under expected sea conditions, in accordance with transport procedures.

iv) Maintain the bending radius and tension within the limits specified by the cable fabricator throughout the transport.

v) Distribute the cable's weight strategically to maintain vessel stability.

vi) Perform a detailed review of anticipated weather conditions and vessel route prior to departure.

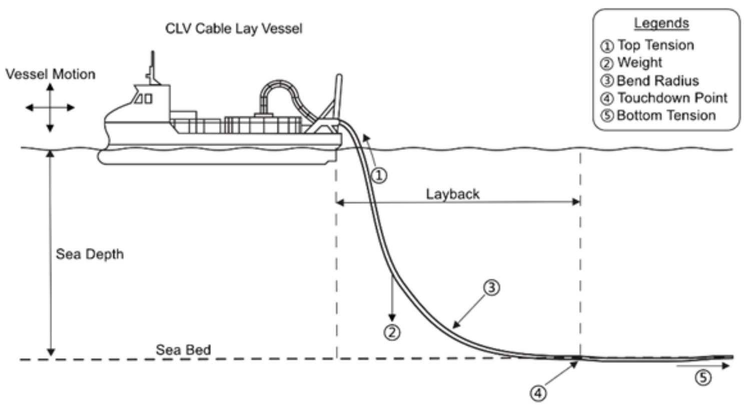
11 Cable installation

Cable installations are to be carried out in accordance with a well-structured procedure and installation methods tailored to the specific site conditions. This involves detailed planning of the cable route to minimize environmental impact, enhance cable protection and extend service life. The procedures also account for unexpected conditions such as seabed changes or obstructions and include clear guidelines for deploying cable burial equipment, along with monitoring and control measures. Additionally, the evaluation of marine and seabed survey data, together with compliance with protective measures and standards, contributes significantly to successful installation.

11.1 Cable laying

Once the site is ready, the cable can be laid following the planned procedures and design. The cable-laying vessel (CLV) crew is to have details about vessel and cable positions, landing location, speed, and tension parameters. Monitoring the catenary, the curve formed by the cable between the CLV and the seabed, is important for tracking the forces acting on the cable. The cable's touchdown point can be monitored using an ROV or a catenary scanner. For more accuracy, finite element software can be used to model the cable's behavior rather than relying on the catenary assumption.

Figure 1
Cable Lay Example



The following data is to be monitored and logged during cable laying:

i) Vessel position

ii) Vessel speed

iii) Catenary angle/departure angle

iv) Cable tension

v) Cable pay-out speed

vi) Touch down location

vii) Calculated residual tension

When planning the cable laying operation, it's important to define the target catenary angle, target residual tension, and minimum residual tension, all with a safety margin consistent with the cable's specifications. The cable is to be laid within acceptable top and bottom tension limits, confirming that the minimum bending radius is not exceeded and that crush/squeeze loads remain within allowable limits.

The cable pay-out rate is to be controlled, and all equipment handling the cable is required to synchronize.

i) Turntable(s)

ii) Pick up arm.

iii) Caterpillars (master, slaves, and backup).

iv) Cable ways.

v) Bundling equipment.

Before starting any cable lay operation, all equipment is to be inspected in accordance with relevant standards, and necessary maintenance is to be performed. A cable trial using a dummy cable may be conducted prior to the actual loading operation.

During cable laying, progress is to be monitored and documented in daily reports. Log all events, including start/stop times, equipment breakdowns, cable tension, touchdown position, cable angle at the vessel, weather conditions, vessel heading and speed, position, nearshore tidal trends, and bathymetry in is tow water. Additionally, all data is to be correlated with cable meter markings and KP (kilometer post) values.

If operation restriction conditions are exceeded, the cable laying operation is to be transferred to a controlled state, and the installation program includes guidelines for suspending, abandoning, and restarting activities during the installation process.

11.3 Jointing

When cables in subsea areas require repair or connection, cable jointing may become necessary. Joints can be used for both single-core and three-core cables and accommodate various insulation materials. These joints are performed per the fabricator's guidelines and fall into two main types: factory joints and repair joints. Repair joints are further classified as flexible joints or rigid joints.

Flexible joints connect the conductors of the two cable ends using welding, brazing, or a connector ferrule to achieve a flush electrical connection. The insulation system is then rebuilt layer by layer, forming well-defined interfaces with the existing cable layers. Once the insulation is restored, the screening, sheathing, and armor layers are reinstated. The final joint has approximately the same diameter as the original cable and can be handled using standard cable machinery. Flexible joints may be manufactured in a factory or assembled on-site.

For flexible joints, continuity of any metallic sheaths or screens is to also be reinstated. However, this may slightly increase the joint's dimensions and locally reduce flexibility.

Rigid joints use prefabricated insulation sleeves and are not flexible. The assembly is completed with watertight barriers, such as metallic encasings or heat-shrink tubes. The outer enclosure is typically a metallic cylinder firmly connected to the cable armor. Rigid joints are generally quicker to install than flexible joints because they do not require complex temperature or pressure processes.

If the subsea cable includes fiber optic elements, the optical fibers are spliced separately in an external fiber optic splice box.

Workers performing jointing are required to be properly trained and hold the relevant certifications.

Typical procedures for factory jointing and repair joints are described in CIGRE TB 490 and CIGRE TB 496.

11.5 Remedial and repair during installation

Subsea power cable installation is a complex and high-risk operation, and remedial and repair work is often required. Damage can result from many causes, including environmental conditions, mechanical stress, handling or storage errors, or technical challenges, and may require immediate corrective action. Common issues encountered during installation include mechanical failure, improper cable handling or storage, incorrect cable positioning or burial depth, excessive cable tension and stress, water ingress or insulation damage, subsea equipment damage, joints or splice failures, and unexpected geotechnical conditions.

Typical remedial and repair activities during installation, including the following:

i) Cable splicing and repair:
If a cable section is damaged during installation, subsea technicians will remove the damage portion, prepare and clean the cable ends, and restore continuity using specialized connectors, joints, or splicing kits. All repairs are to be recorded, and drawings and documentation updated accordingly.

ii) Repositioning and reburial:
If the cable is laid incorrectly or does not meet burial depth requirements, remedial work may involve repositioning the cable to the correct location or re-burying it to the required depth using subsea ploughs, ROVs or trenching machines.

iii) Tension relief and stress management**:**
Managing tension during installation is important to prevent potential damage. If excessive cable tension is detected, remedial actions may include re-spooling the cable to relieve stress or adjusting the installation rate to mitigate further risk. In cases where significant mechanical damage occurs, it may be necessary to re-splice or replace affected cable sections to achieve system integrity.

iv) Protective coverings**:**
Where the cable is at risk of external damage, additional protection may be applied, such as rock dumping, concrete mattresses, or specialized armoring to shield the cable.

v) Inspection and testing**:**
After installation and any necessary remedial or repairs, the cable is to undergo thorough testing to confirm functionality (see 6/3 for detailed testing procedures), Tests may include electrical measurements, integrity checks, and subsea inspections using ROVs to verify the effectiveness of repairs.
For detailed remedial and repair guidance, refer to 7/5.11, 7/5.13 and CIGRE TB610 and CIGRE TB 883.

13 Cable pull-in operation

Project-specific pull-in procedures are to be developed based on a detailed analysis of factors such as friction, soil resistance, and loads from centralizers or connectors. Maintaining control over the cable lay configuration and installation loads is necessary to stay within design limits. The procedure is to account for dynamic load variations and include monitoring of the design parameters. Both first and second end pull-ins are to follow the method through project-specific evaluations.

Typically, the sequence of events in a pull-in operation is as follows:

i) The first end of the cable is pulled in.

ii) The cable is initially secured at a temporary hang-off point.

iii) The installation vessel lays the cable away from the hang-off point toward the next location.

iv) A bight of cable is laid either onto a quadrant or onto the seabed.

v) The second end of the cable is pulled in, and the bright or quadrant is managed from the installation vessel.

vi) The second end is temporarily secured at the hang-off point.

vii) Cable burial begins with tension in the cable released during the burial process at both ends via the temporary hang-offs.

viii) Once burial operations are complete, permanent hang-offs are installed.

ix) The cable is stripped, routed, and cleated as applicable.

x) Termination or jointing is completed.

During the installation process, electrical and optical tests can be conducted to check for damage, especially since some time may have elapsed between the various stages of installation.

13.1 Cable pull-in at offshore asset

Cable pull-in operations at an offshore asset is to follow the agreed procedures and aligning with installation plans specified in 5/1.1, as well as the approved designs, these requirements typically include pulling the cables onto the platform, hang-off, running the cables or cores within the platform, securing cables to the platform structure, and terminating the ends for connection to the GIS.

Cable operations on offshore platforms are to comply with the cable fabricator's handling recommendations, particularly regarding minimum bending radius, maximum side-wall pressure, and maximum tensile load. Continuous monitoring and logging of pulling tension are recommended to confirm it remains within the cable's mechanical limits, thereby preventing overstress or damage.

The following points to be considered for the pull-in operation at the offshore asset:

i) Liaising with offshore asset owners regarding facilities and operations on the assets.

ii) Identify all fixing points for the cables and any fixtures or fittings required on the offshore cable deck or topsides.

iii) Confirm availability of all tools and equipment necessary for installation, including a pull-in winch, power for the winch, winch wire, and any running gear such as blocks and shackles.

iv) Fit a centralizer and drop zone protection to each cable pulled in.

v) Estimate the force required to pull in the cable and communicate these to the foundation and designers.

vi) Recode video of any work related to pulling cable into a J-tube as applicable.

vii) Use a messenger wire to guide the pulling line through the J-tube, I-tube or structural entry hole where possible.

viii) Check the angle between the bell mouth and seabed and confirm adequate bell-mouth clearance.

ix) Continuously monitor the entire pull-in operation to confirm all relevant parameters remain within specified limits.

x) Provide cable protection during pull-in operation where required.

13.3 Cable pull-in at landfall

Cable pull-in operation at landfall is to follow the agreed procedures and follow installation plans specified in 5/1.1, as well as the approved designs. Landfall conditions vary from rugged cliffs to sandy beaches and sensitive salt marshes, and each situation presents its own challenges. Typical landfall operations include mobilizing equipment, preparing the landing site, positioning the installation vessel, pulling in the cable, burying the cable, and demobilizing once the work is completed. All landfall activities are to be carried out in accordance with the design and project plan.

Several methods exist for subsea cable installation at landfall, depending on the site's specific conditions. A common approach is the open trench method, often used for transitioning subsea cables from offshore to onshore. This involves excavating and burying the cable or conduit directly into the beach or within a protective conduit. In some cases, subsea cables may be laid in an open trench on the beach or coast without additional protection.

Alternatively, horizontal directional drilling (HDD) is frequently employed for landfall construction. This method requires planning and execution, with success largely dependent on a well-designed site investigation plan. Considerations include the drill bit's depth and length and the precise location of entry and exit points.

Geological surveys and site investigations play a key role in determining the most suitable installation method for subsea power cables. These studies assess environmental and geological conditions to support proper cable deployment. Each installation method requires specific geological surveys to facilitate correct installation, considering trench stability, soil characteristics and environmental impacts.

Key considerations for cable landing preparation:

i) Protect the cable and conduit/pipe during the pull-in process.

ii) Proper size winches, rollers, and other pulling devices, considering all relevant pulling parameters.

iii) Select and assemble pulling devices correctly.

iv) Maintain effective coordination and communication throughout the landing process.

v) Position the joint pit with attention to mechanical and thermal factors.

vi) Obtain special permits if the landing point is in an environmentally sensitive area.

vii) Evaluate long-shore currents and their impact on the operation.

Seabed depth and environmental conditions are important considerations when preparing for a cable pull-in. The objective is to minimize the distance between the vessel and the shoreline to improve control of the cable during pull-in. The vessel operates as close to shore as it is practical without compromising maneuverability.

Key requirements for subsea cables pull-in during landing:

i) Attach a suitable pulling device to the cable. For high pulling forces, use a pull-in head with the cable's main tensile-strength member securely terminated. For lighter pulling forces, a flexible pulling grip or sleeve may suffice.

ii) Use monitoring and measuring devices during pulling operations to confirm that the cable tension and pulling force remain within allowable ranges. Monitoring and measuring devices are to be calibrated.

iii) Select and properly pulling equipment (winches, rollers, cable guides) to handle the expected tension and forces.

iv) Verify the pulling device is correctly and securely assembled on-site, with proper alignment to minimize stress on the cable.

v) Use a messenger wire where applicable.

vi) Establish and maintain clear communication among all parties involved.

vii) Provide cable protection during pull-in where required.

viii) Confirm that the installation vessel's operation is approved by its classification society.

ix) Evaluate the effect of buoyancy support on cable tension and verify that it remains within the permissible limits.

x) For HDD or other deep installation methods, consider specialized thermal backfill materials to manage heat dissipation if required.

xi) Prepare for potential challenges, such as unexpected weather, equipment failure, or unanticipated ground conditions, and maintain contingency plans and backup resources.

Select first-end or second-end pull-in at landfall based on actual requirements and project-specific assessment.

15 Hang-offs at offshore assets

Cable hang-offs at offshore assets are to follow the agreed procedures and align with installation plans specified in 5/1.1, as well as the approved designs. Hang-offs are positioned on the offshore asset (for example, an offshore substation, turbine support, or other structures) at the top of the J/I-tube (as applicable) near the cable termination points. Their purpose is to securely anchor the cable by transferring all mechanical loads from the armor to the support structure throughout the cable system's design life, without compromising cable integrity.

Hang-off operation typically consists of two main steps. The first is a temporary fixation that secures the cable immediately after the pull-in. It is important that this temporary fixation prevents any unintended slippage during the period before the permanent hang-off is installed. The second step is the permanent fixation, which secure the cable for its service life. The permanent hang-off is to also allow for an electrical connection between the cable armor and the structure's grounding/earthing systems.

Depending on the installation sequence, it is advisable to release cable tension in a controlled manner after disconnecting the temporary hang-off, before installing the permanent hang-off. This allows the cable to settle more effectively on the seabed near the J/I tube entrance.

17 Cable protection and anchorage system at sea/land transition joint

The sea-land transition joint is to be constructed in accordance with the approved designs, and the cable pulling operation is to follow the approved plan. Typically, the cable armor is anchored to transfer mechanical loads to the joint foundation, where applicable, to the HDD pipe flange, extending system life and maintaining integrity. This anchoring also provides a connection between the armor and the land-based grounding system. Depending on site conditions, particularly on steep slopes, additional anchoring may be required. After pulling the cable into the joint pit, secure it to prevent movement. Once all mechanical and electrical work is completed, restore the site as specified in the project plan.

19 Protection for Cable

Protection for cables is to meet the approved designs of 3/11 and comply with the installation plans specified in 5/1.1. Protecting subsea cables is particularly important in areas with high human-activity, such as shipping lanes and fishing zones, where cables are exposed to physical risks from anchors, fishing equipment, and other maritime operations, Burial is a commonly used protection method, although it may not be necessary in deep waters or for short segments that can be repaired easily.

Determining the optimal burial depth requires balancing the protection needs, environmental considerations, and project costs. This balance is particularly important in environmentally sensitive areas, such as coral reefs. Proper soil management is important for controlling cable temperatures, as burial depth and the type of backfill directly influence heat dissipation.

Cable protection techniques vary by location. In high-risk zones, such as shore approaches, shallow waters, or shipping channel crossings, additional measures may include rock dumping, concrete mattresses, or trenching to safeguard the cables. Conversely, in low-risk areas, cables may be laid directly on the seabed when no significant hazards exist.

Key considerations for cable protection include providing adequate mechanical protection, managing thermal performance, and addressing local environmental constraints. Burial depth may need adjustment in areas with heavy maritime traffic, large vessels, or dynamic seabed conditions. Over time, supplemental or enhanced protection measures may also be required to maintain cable integrity and stability.

19.1 Cable burial

Cable burial methods can be divided into three solution types: pre-lay trenching, simultaneous lay and burial, and post-lay burial. Each method suits different environmental and operational conditions and is selected based on factors such as seabed composition, required burial depth, and the protection needs of the cable.

i) Pre-lay trenching:
Pre-lay trenching involves excavating a trench along the cable route before the cable is installed. This method is often used where the seabed requires preparation due to challenging soil conditions (for example, hard clay, compacted sand, or rocky areas). Specified trenching equipment is typically used. After the trench is created, the cable is laid into the prepared trench, and the excavated material may be used to cover it. Pre-lay trenching provides a stable and protected environment for the cable, making it suitable for difficult seabed conditions.

ii) Simultaneous lay and burial:
In simultaneous lay and burial, the cable is buried as it is being laid on the seabed. This method is commonly used in softer soils, such as sand or silt, where the seabed can be easily disturbed. Specialized equipment (plows or jetting tools) is used to create a trench and bury the cable in one continuous operation. Simultaneous lay and burial offer speed and efficiency, reducing the time and cost, and is often preferred where rapid installation is necessary, and seabed conditions allow.

iii) Post-lay burial:
Post-lay burial involves first laying the cable on the seabed, followed by burial at a later stage. This method is typically used where simultaneous lay, and burial is not feasible due to seabed conditions or operational constraints. After laying, trenching or jetting equipment is used to bury the cable. Post-lay burial provides flexibility, allowing precise cable positioning before burial. It is often used in dynamic seabed environments or where precise placement is required.

Each method has advantages and is to be selected based on project specific requirements. Pre-trenching is ideal for challenging seabed, while simultaneous trenching and burial offers speed and efficiency in softer soils, while post-burial provides flexibility for precise cable placement. The correct choice promotes protection while minimizing the risks from external threats and environmental factors. When mechanical backfilling is required, it is to be performed to minimize the potential for cable damage, and the operation is to be properly monitored.

In general, the cable is protected by burial in the seabed. The laying and burial process is to be controlled and monitored, including parameters such as burial depth and cable position.

Typical control and monitoring devices used during laying and burial activities (installed on vessels or ROVs), include:

i) Redundant GPS systems.

ii) Precision echo sunderer.

iii) Data acquisition and display system.

iv) High precision acoustic tracking system (USBL).

v) Logging system for all cable burial surveys during installation.

vi) Two acoustic scanning profilers.

vii) Precision acoustic altimeter

viii) Cable tracking device

ix) Imaging sonar system.

x) CCTV and lighting system.

Normally the following data is to be documented:

i) ROV or similar vehicle position/cable position in geographical and grid co-ordinates, KP and distance offline, cable tracker parameter and any other pertinent information.

ii) Trech configuration, including cable depth of burial (DOB) from top of cable to mean undisturbed seabed level and depth of cover (DOC).

iii) Any irregularities near the cable (rocks, boulders, debris), start and end of cable protection sleeves, changes in seabed conditions, start and end of trench transitions.

iv) Crossings with other assets.

v) Joints and repair positions.

If the cable is trenched in more than one pass, the cable burial survey report is to document the results after each pass.

19.3 Non-burial protection

In areas where burial protection is not feasible due to seabed conditions or environmental constraints, non-buried protection methods are necessary to achieve the integrity of subsea power cables. These methods shield cables from external threats such as fishing activities, anchoring, and other mechanical impacts, while also providing stability in challenging seabed environments.

Key requirements and methods for non-buried protection of subsea power cables:

i) Rock dumping: Place graded rock or gravel over the subsea cable to create a protective layer. The rock layer acts as a physical barrier against external impacts (for example, trawling or anchoring) and helps stabilize the cable on the seabed.

ii) Concrete mattresses: Install pre-cast concrete mattresses over the cables to provide impact protection and distribute loads evenly. Concrete mattresses also add weight and restraint, reducing the risk of cable movement due to currents or other environmental forces.

iii) Protective covers or shells: Use articulated pipe covers, split shells, or similar protective enclosures to encapsulate the cable. These covers provide enhanced impact resistance and additional weight for stabilization and are useful where rock dumping or mattresses are impractical.

After installation of non-buried protection, perform a post installation survey to verify compliance with the approved designs. The post installation survey is to confirm that the protection measures are correctly implemented and that the cable is adequately shielded from potential risks.

19.5 Asset crossings

Asset crossings of offshore subsea power cables are to be carried out according to the approved plan and designs. These requirements typically address the protection, stability and integrity of cables when crossing other assets such as pipelines, other cables or subsea facilities.

Key requirements for asset crossings:

i) Crossing agreement: Establish a formal agreement with the owner of the existing infrastructure. The agreement is to define responsibilities, procedures, and standards for installation, access rights and maintenance obligations.

ii) Separation and clearance: Maintain an adequate distance between the subsea power cable and the crossed infrastructure to prevent mechanical interference and to accommodate thermal expansion or other movements. Minimum separation distances are to be defined based on the type of infrastructure being crossed.

iii) Protection methods: Implement project-specific protection measures at the crossing point, such as:

a) Concrete mattresses: Provide a stable platform and physical barrier between the cable and the existing infrastructure.

b) Rock dumping: Create a protective layer to prevent direct contact and reduce the risk of damage from external forces.

c) Protective covers or shells: Use articulated pipes or other protective casings around the cable to shield it from impact.

iv) Crossing angle: Where possible, aim for a perpendicular or near-perpendicular crossing angle to minimize the interaction length and reduce the risk of mechanical damage.

v) Anchoring and stability: Confirm the cable is securely anchored and stabilized at the crossing location to prevent movement due to currents or external forces. Stability is necessary to avoid strain on either asset.

vi) As-built documentation and post-installation surveys: Perform as-built post-installation surveys to confirm that the crossing has been executed by the approved design. Document the final position, protection measures, and any deviations from the planned design.

vii) Compliance: Verify that the crossing design and installation complies with all relevant regulatory standards and guidelines, including those of local authorities, industry bodies, and environmental agencies.

21 Post-installation survey

After the installation, a post-installation survey is to be conducted in accordance with the approved installation plans in 3/1.1, and applicable approved designs. The purpose is to verify that the as-laid position of the cable system complies with the approved designs, confirm the system's integrity, and inspect for any damage resulting from the installation process. The post-installation survey also documents any deviations from the original design and identify potential risks that may require mitigation.

The scope of the post-installation survey may include:

i) Laying and burial verification: Confirm that the cable was laid along the intended route and that the burial depth meets the approved design, including assessment of varying seabed conditions and protection against external threats.

ii) Crossing inspections: Verify cable integrity at all infrastructure crossings and confirm protection measures, (e.g. mattresses or grout bags) were applied per the approved crossing designs.

iii) Rock placement and artificial backfill: Assess areas with rock placement or artificial backfill to verify that stability and coverage meet the approved designs and minimize seabed erosion.

iv) Cable protection structures: Inspect and confirm correct installation and positioning of any additional cable protection structures specified in the design.

v) Deviation identification and reporting: Identify and document any deviations from the original design or installation plans, including recommendations for corrective actions and assess impacts on performance.

vi) Documentation: Record the as-laid position of the cable system using geophysical and geotechnical survey methods to enable accurate comparison with the planned route and to support future operations or maintenance.

As a minimum, the post-installation survey is to include:

i) Detailed bathymetric data to confirm the cable's position and burial depth.

ii) Visual inspections using ROVs or other suitable equipment to assess the physical condition of the cable and its protection.

iii) Verification of burial depth.

iv) Inspection of all crossings and associated protection measures.

v) Documentation of all findings in a comprehensive post-installation survey report, including georeferenced maps, videos, and photographs.

SECTION 6
Commissioning and Testing

1 General

Commissioning and testing are key steps in the deployment of subsea power cables, confirming that all systems are properly installed, terminated, and functioning in accordance with the approved design, fabricator requirements, and approved commissioning procedures and instruction manuals. The preparation of these procedures is to consider the guidelines outlined in IEC82079-1. Key activities during this phase include on-site termination of subsea power cables and associated fiber optics after the cable has been laid along its offshore route. This involves preparing the cable ends for connection, configuring communication lines, and establishing power transmission pathways.

Testing is conducted on-site to verify the integrity and performance of the offshore subsea power system. Testing follows established test procedures and test plans. These tests are to assess the cable's integrity, insulation performance, and the effectiveness of the protective layer under operational electrical conditions. They also detect any faults or abnormalities in a cable or transmission line. and confirm the functionality of monitoring systems. By identifying and addressing potential issues before the system is fully operational, the commissioning and testing process contributes to reliable performance.

3 Commissioning and Site Testing

Prior commencement of commissioning, it is to be confirmed that the installation of subsea power cables, including all mechanical work and the hang-off process, has been fully completed. Armored wire terminations are to be securely electrically earthed at the designated earthing points using project-approved earthing assemblies. Special attention is to be given to the installation of these assemblies to confirm that they minimize the risk of corrosion and provide long-term protection against electrical faults.

An inspection and test plan (ITP) and checklists is to be prepared by the client and submitted to ABS for review prior to the commencement of the commissioning tests.

Subsea power cables are to be equipped with termination kits that are either approved or recommended by the cable fabricator and are specifically suited for the intended termination point or application. These kits are to undergo rigorous testing and be designed to withstand the specified voltage levels, providing reliable insulation and protection against electrical stress. Installation is to follow the fabricator's guidelines to comply compatibility with both the cable type and the environmental conditions at the installation site.

For optical fibers embedded within the subsea power cables, connections are to be made in a splice box that complies with the approved design. The splice box is to offer mechanical protection and environmental sealing to maintain fiber integrity, preventing issues such as moisture ingress or physical damage.

The installation, commissioning and testing of termination kits is to be carried out only by qualified and experienced technicians. These technicians are required to have specific training for the type of termination kit used and hold the necessary certifications. Additionally, the tools recommended by fabricator, including calibrated measurement instruments with valid certification, where applicable, are to be used for proper cable handling, termination, and installation. The use of incorrect tools could compromise both the performance and integrity of the installation. For further guidance, refer to CIGRE TB 476 and CIGRE TB 560.

Once the subsea cable system is fully installed, the entire subsea cable system, including subsea power cables, accessories, optical fibers, splices and connectors, is to be tested. As part of commissioning procedure, in addition to visual inspection, newly installed cables and related components are to undergo both electrical and non-electrical testing after the cable system is fully installed. These tests, as outlined in table 1, are intended to confirm that the cable system is free from obvious faults that could impact its lifespan, such as damage incurred during transportation or issues arising from installation workmanship.

The purpose of these tests is to verify that the cable system meets operational standards and performs reliably under expected conditions. Different voltage levels and cable configurations may require different testing methods. Before testing begins, a suitable method is to be selected based on the specific cable type, system requirements, and the responsibilities of all relevant parties clearly defined. Commissioning tests for subsea power cables are to include the following, as applicable to each cable type.

Table 1
Commissioning Tests

Tests	*Description*	*Applicable Standards*
High Voltage (HV) Testing	Verifies the dielectric strength of the insulation by applying high voltage. Detects fabrication defects, installation damage, or potential insulation failures.	IEC 60840, IEC 63026, IEC 62067 (Table 4); CIGRE TB 496 (Section 7.1), CIGRE TB 852 (Section 11.1)
Partial Discharge (PD) Measurement	Measures partial discharges within the cable's insulation under high voltage. Identifies weak spots that may degrade over time and cause failure.	IEC 60840 (Section 16.3.1.2), IEC 62067 (Section 16.3.2), CIGRE TB 728
Time-domain Reflectometry (TDR) Testing	Detects faults, discontinuities, or anomalies by analyzing signal reflection. Help pinpoint fault locations.	IEC 63026 (Section 13.5), CIGRE TB 490 (Section 11.2), CIGRE TB 496 (Section 7.3), CIGRE TB 852 (Section 11.3)
Sheath Integrity Testing	Verifies the integrity of the cable's outer sheath to detect breaches, cuts, or tears, helping to maintain protection against mechanical damage and environmental factors.	IEC 60229
Optical Fiber Testing	Uses Optical Time-Domain Reflectometry (OTDR) to test embedded optical fibers, confirming their integrity and communication functionality.	ITU-T G.976
Continuity/Electrical resistance Testing	Confirm electrical continuity of conductors and checks for any open circuits or faults.	IEC 60840, IEC 60228
Insulation Resistance Testing	Measures insulation resistance to identify leakage paths or weaknesses that could lead to electrical failures.	IEC 60229, IEC 60840
Cable Identification Testing	Confirms correct identification of cable cores to prevent misconnections during installation and operation.	IEC 60840, IEC 60228

New test technologies or additional post- installation tests may be agreed upon between fabricator and client. These may include Near Power Frequency (NPF) resonant test, Very Low Frequency (VLF), damp AC (DAC), and DC voltage test for HVDC cables, among others. All such tests are to be clearly detailed within the commissioning and testing procedures and associated test plans.

Upon completion of all tests, detailed reports with handover check lists are to be generated to document the results. These reports are to include the test methods used, test conditions, measured values, and any anomalies or deviations observed. The documentation will serve as a reference for future inspections, maintenance activities, and any troubleshooting throughout the operational life of the cable system.

SECTION 7
Operation and Maintenance

1 General

The subsea power cable system operates in accordance with the approved design, operational requirements, and monitoring and maintenance plan. This section outlines the operation and maintenance activities, confirming that all procedures meet health, environmental and system availability criteria.

3 Operation and maintenance planning

The cable system is to be operated in accordance with the operational requirements defined in the approved design and the fabricator's operation and maintenance manual/plan. Performance criteria covering health, environmental protection, and the required system availability are to be clearly defined.

A comprehensive operations and maintenance plan to be established in coordination with cable system designers, cable fabricators, and relevant asset stakeholders. The plan is to focus on proactive risk management throughout the cable system's operational life. Detailed planning is to be conducted prior to operation, with requirements that are to be regularly reviewed and updated to address emerging risks or changing conditions. At a minimum, the O & M plan is to address the following key elements:

i) Development of a detailed maintenance plan, including in-service inspection and test plans (ITPs), repair procedures, and cable protection measures.

ii) Operation of the subsea power cable is to comply with the design, functional requirements, and fabricator recommendations, with all operational parameters aligned to the system's intended purpose and limitations.

iii) A clear description of the system and its operational principles is to be included.

iv) Health and safety standards are to be prioritized to minimize risks to personnel and equipment. Environmental protection measures are to be incorporated to mitigate impacts on marine ecosystems.

v) System monitoring and performance evaluation, and maintenance schedules are to be included to promote high system availability and minimize downtime.

vi) A monitoring system is to be in place to track cable performance, detect faults, and provide diagnostics to address potential issues before escalation.

vii) Procedures for handling terminations, joints, and ancillary components are to be specified.

viii) Fault detection, isolation, and response protocols are to be established.

ix) A spare parts strategy and inventory control plan are to be developed.

x) Operational instructions for normal and contingency conditions are to be provided.

xi) Procedures for responding to alarms and emergencies, along with a repair strategy to minimize service, are to be included.

xii) All operations, maintenance, and inspection activities are to be documented, with records maintained for future reference and compliance.

xiii) Personnel responsible for operating and maintaining the subsea cable system are to be adequately trained and competent, with a clear understanding of the specific requirements and associated risks.

5 Monitoring and Maintenance

During cable system operation, continuous monitoring of electrical, mechanical, and environmental parameters is required to confirm that the system remains within its defined operating limits and to promptly identify any abnormal conditions.

As outlined in CIGRE TB 279, here are three maintenance approaches:

i) Corrective maintenance: Involves repairing or replacing components that are broken or malfunctioning. This requires fault detection, accurate diagnostics, availability of spare parts, and deployment of skilled technicians equipped with the necessary tools to minimize system downtime.

ii) Time-based maintenance: Preventive maintenance performed according to a predetermined schedule. This includes routine maintenance and interventions based on the system's operational history to maintain optimal performance throughout its service life.

iii) Condition based maintenance: Preventive maintenance triggered by specific indicators or conditions suggesting that a component is likely to fail. This approach enables targeted interventions before failures occur.

These maintenance strategies, along with the fabricator's recommendation, contribute to enhancing the cable system's integrity by addressing both routine servicing and specific operational conditions.

Condition-based maintenance may also include actions required to restore the cable system to operational service after a failure or potential failure, such as damage from an anchor strike or changes in seabed topography, in such cases, assessment and additional protective measures may be necessary to confirm continued operational integrity.

5.1 Monitoring

Monitoring subsea power cables supports efficient and long-term operation by detecting changes in operating parameters and allowing timely mitigation measures, such as adjusting operational setting, it also provides valuable input for maintenance activities. Monitoring activities are to be planned, executed, reviewed and documented in alignment with both operational and approved designs.

5.1.1 Parameter monitoring

In general, the following parameters are to be monitored where applicable:

i) Electrical parameters: voltage, current, frequency, power factor, power etc.

ii) Thermal parameters: temperature.

iii) Mechanical parameters: tension and strain, bending, vibration.

5.1.2 Monitoring and inspection techniques

The following are potential monitoring and testing techniques that can be applied to subsea cable systems during the operational phase:

i) Electrical parameter monitoring (voltage, current, frequency, power factors, power, insulation condition).

ii) Mechanical parameter monitoring (e.g., stress, tension, strain, movement etc.).

iii) Distributed Temperature Sensing (DTS).

iv) On-line Partial Discharge (PD) Monitoring.

v) Distributed Acoustic Sensing (DAS).

vi) Distributed Strain Sensing (DSS).

vii) Distributed Temperature and Strain Sensing (DTSS).

viii) Optical Time-Domain Reflectometry (OTDR).

ix) Bridge Measurement Methods.

x) MEMS-IMU-Based Monitoring.

If necessary, other techniques may be employed, such as fault detection systems, monitoring of marine conditions, corrosion and moisture intrusion, etc.

5.3 Time based maintenance

Time based maintenance for subsea power cables supports long-term performance, system integrity by addressing wear, degradation, and operational stresses at scheduled intervals. These activities are typically planned at fixed intervals and involve proactive measures to prevent failures, reduce downtime and extend service life. The following activities is to be included as part of a time-based maintenance program:

i) Route inspections are to monitor burial depth, cable entry and protection, identify free spans, and check for signs of damage, obstructions or exposure, this is especially important in areas with dynamic seabed conditions such as shifting sand dunes or sediment movement.

ii) Regular inspections of transition joints between subsea and land-based systems, as well as with other infrastructures (e.g., pipelines or cables), are strongly recommended. These areas are particularly vulnerable and are to be examined for wear, corrosion, and connection integrity.

iii) Hang-offs, fixing clamps, fire-retarding passages, termination, corrosion earth-connections and bending restrictions on platform and the supporting structure is to be regularly inspected.

iv) Components such as buoyancy modules, spiral plates, protective sleeves are to be checked for wear and integrity.

v) Maintaining the integrity of the scour protection around the cable is vital to prevent excessive mechanical forces. Damaged or eroded scour protection can lead to dynamic forces and accelerated fatigue, increasing the risk of failure.

vi) Periodically review data from real-time monitoring systems, as applicable, such as Distributed Temperature Sensing (DTS) and Distributed Acoustic Sensing (DAS), Distributed temperature and strain sensing (DTSS).

vii) Periodic testing, including insulation resistance tests and partial discharge (PD) analysis, helps identify potential issues before they escalate into major failures.

viii) A well-timed maintenance schedule includes strategies for rapid response to potential failures. The ability to respond quickly can help minimize outages and reduce associated risks.

By incorporating these elements into a time-based maintenance program, operators can reduce the likelihood of unexpected failures.

5.5 Condition based maintenance

Condition based maintenance does not follow a fixed schedule but is typically triggered by observations made during routine maintenance, monitoring, or diagnostic measurements. These triggers may include indicators such as online monitoring systems alerts, partial discharge (PD) detected at termination points, dielectric loss angle measurements, abnormal temperature readings, unusual strain or vibration measurements, sheath testing results, or findings from thermal inspections. When such issues arise, maintenance of subsea power cables becomes necessary and requires specific procedures and capabilities to address faults, damage, or operational disruptions, the fault location process can refer to 7/5.7 and location techniques are detailed in 7/5.9.

The safety of personnel involved in maintenance operations is always the top priority. Fault location activities are to strictly follow national, international, and company specific safety regulations. Only personnel with proper training and authorization are to perform these tasks.

Training requirements for working in high-voltage environments are defined by international standards, national electrical codes, and company-specific policies. In some cases, maintenance may need to be carried out in specialized areas, each with its own training and certification requirements depending on the circumstances.

All personnel are required to possess the necessary qualifications and certifications for their assigned tasks to maintain safety and regulatory compliance.

5.7 Fault location

If maintenance is required, the initial step involves locating the fault. The workflow for cable fault location (refer to CIGRE TB 773) typically includes the following steps:

i) Fault diagnosis.

ii) Fault recognition.

iii) Preliminary fault localization.

iv) Cable tracing.

v) Pinpointing the exact fault location.

vi) Cable recognition.

vii) Repair.

5.9 Location technique

Cable fault location techniques are generally classified into two main categories: pre-location and pinpointing.

i) Pre-location involves testing the circuit from the cable terminations to estimate the distance to the fault, providing a rough indication of its location. This step helps to narrow down the potential area.

ii) Pinpointing is performed after pre-location to accurately determine the fault's exact location within the identified area.
For further details on pre-location and pinpointing techniques, refer to IEC 60050 and CIGRE TB 773 for more details.

Table 1 below provides a summary of potential fault location techniques.

Table 1
Fault location techniques

Fault Location Technique	*Application*	*Limitations*	*Online /Offline*	*Fault Type*	*Suitable for*
Time Domain Reflectometry (TDR)	Locate electrical faults such as short circuits, open circuits, or conductor breaks	Reduced accuracy for very long cables or complex multi-core cables; not suitable for optical cables.	Offline	Short circuits, open circuits, conductor breaks	Power cables

Fault Location Technique	*Application*	*Limitations*	*Online /Offline*	*Fault Type*	*Suitable for*
	by analyzing reflected signals.				
Burn Down Techniques	Identifying insulation faults or high-resistance faults in power cables.	Risk of further cable damage if improperly applied; destructive method.	Offline	high-resistance insulation faults	Power cables
Arc Reflection Method	Locates faults involving insulation breakdown by detecting arc-generated reflections.	Requires stable arc generation and specialized equipment.	Offline	Insulation breakdown, high-voltage faults	Power cables
Voltage Decay Method	Identify insulation faults by monitoring voltage decay characteristics.	Interpretation can be difficult for long cables	Offline	Insulation faults, leakage paths	Power cables
Impulse Current Method	Locates high resistance faults by injecting high energy current impulses.	May impose thermal and electrical stress on the cable	Offline	High-resistance faults, short circuits	Power cables
Frequency Domain Reflectometry (FDR)	Detects impedance changes caused by insulation degradation or high-resistance faults.	Less effective for low-resistance faults.	Offline	Insulation degradation, impedance changes	Power cables
Bridge Method	Locates faults by resistance measurement between conductors or conductors and sheath.	Requires access to both cable ends, limited resolution.	Offline	Continuity faults, high-resistance faults	Power cables
Acoustic Method	Detects mechanical damage or fault-induced acoustic emissions using sensors.	Limited sensitivity; requires sensor installation.	Online (with sensors)	Mechanical damage, cracking, stress	Power cables, Optical cables
Magnetic Field Methods	Identifies faults by measuring magnetic fields generated by fault currents.	Ineffective for very high-resistance faults; requires specialized sensors.	Online (with sensors)	Short circuits, leakage faults	Power cables
Sectionalizing Methods	Isolates cable sections to narrow down fault location.	Requires disconnection and operational interruption.	Offline	Multiple faults, section isolation	Power cables
Impulse Magnetometry	Locates faults by measuring transient magnetic fields from impulse currents.	Requires sensitive instrumentation and fault current generation.	Offline	Short circuits, high-resistance faults	Power cables
DC Magnetometry	Detects changes in static magnetic fields caused by conductor damage or deformation.	Limited sensitivity: specialized equipment required.	Offline	Conductor damage, high-resistance faults	Power cables
Optical Time Domain Reflectometry (OTDR)	Range limitations for very long links; affected by connector reflections.	Range limitations for very long links; affected by connector reflections.	Offline	Fiber breaks, attenuation, connector losses	Optical cables

A wide range of pre-location and pinpointing techniques may be used with fiber optic cables, including Distributed Temperature Sensing (DTS), Distributed Vibration Sensing (DVS), Distributed Acoustic Sensing (DAS) and Distributed Temperature and Strain Sensing (DTSS).

Before initiating cable fault location procedures, it is recommended to conduct a risk assessment and prepare method statements for the chosen fault-finding techniques.

5.11 Remedial work

Remedial work is to restore subsea cable protection to its original approved design during repair or maintenance activities.

The requirements for remedial work are as follows:

i) Develop a remedial work plan/procedure prior to execution, considering local conditions and site-specific factors.

ii) Define criteria for initiating remedial work, including:

- *a)* Minimum burial depth and cable exposure limits.
- *b)* Electrical performance (e.g., insulation resistance).
- *c)* Mechanical integrity (e.g., minimum bending radius, armor or sheath condition).
- *d)* Thermal performance.
- *e)* Inspection findings.

iii) Conduct a post-remedial survey and inspection (e.g., post-burial/installation survey and testing) to verify compliance with the approved design.

iv) Appy remedial measures such as reburying exposed cables or repairing damaged external protection (e.g., rock berms) in accordance with applicable guidelines such as CIGRE TB 883.

v) Removing excess material where practicable to maintain current-carrying capacity.

vi) Consider additional protection measures if risk exposure increases due to external factors (e.g., fishing activities, or anchor threats)

5.13 Repair

Repair of subsea power cables is to be conducted in a controlled environment with detailed planning, the use of specialized equipment, and procedures customized to the specific cable type. Repairs are to utilize spare cables and accessories as recommended by the fabricator. Personnel performing the repair is to hold verified training and possess relevant experience to subsea cable repairs. For safety, the cable is to be fully de-energized for the duration of the repair, with both ends securely grounded throughout procedure.

Typical repair procedures are organized into the following elements:

i) Repair planning

- *a)* Define operational limiting conditions related to sea state, current, and vessel movements, accounting for uncertainties in weather forecasts.
- *b)* Verify the repair location through site investigation to confirm it is free of obstruction and that seabed conditions are suitable.
- *c)* Plan for potential anchoring requirements and the laydown process for the repaired cable.
- *d)* Where repair quality or environmental constraints introduce uncertainty, consider implementing a derating strategy to prevent excessive thermal loading.
- *e)* Conduct risk assessments addressing environmental, mechanical, and electrical hazards.

ii) Specialized equipment

a) Analysis arrangements and equipment for lifting and lowering the repair bight, identifying key parameters and limiting criteria to be continuously monitored.

b) Use a specialized cable-laying or repair vessel equipped with DP.

c) Employ manipulation tools and cable plows for reburial.

d) Utilize joints, bend stiffeners and bend restrictors suitable for high-voltage applications.

iii) Pre-repair assessments

a) Use fault detection technology (refer to CIGRE TB 773) to identify and locate faults.

b) Inspect cables and assess the extent of damage or seabed conditions.

iv) Cable repair procedures

a) Follow a structured sequence for the repair.

b) Conduct repairs in accordance with CIGRE TB 883 or another recognized standard.

v) Testing and validation

a) Perform relevant tests to verify the integrity of the repair.

b) Confirm the cable's thermal performance meets acceptable thresholds to avoid overheating during operation.

vi) Permitting and compliance

a) Obtain necessary permissions from regulatory authorities, particularly for environmental protection and marine traffic management.

b) Confirm adherence to international standards (e.g., IEC, CIGRE) and local marine regulations.

c) Conduct post-burial and post-installation surveys to verify that the repair meets the approved designs.

d) Document all interventions and repair activities for traceability and compliance.

By adhering to these requirements, the subsea power cable repair process will be executed efficiently, minimizing system downtime and supporting continued operation.

SECTION 8

Independent Third-Party (I3P) Inspection Requirements

1 General

The I3P inspection for offshore subsea power cable projects is undertaken to verify that the cables are fabricated, transported, installed and commissioned in accordance with the agreed scope of work and with applicable industry codes, standards, and relevant ABS technical frameworks and guidance. Upon completion of the I3P activities, ABS may issue an I3P Statement of Fact (I3P SoF) or an I3P Statement of Compliance (I3P SoC), as applicable in accordance with the ABS Guidance Note on Independent Third Party (I3P) Services.

This section covers the key requirements across various stages, including fabrication, transportation, installation, commissioning, testing, operation, and maintenance, to verify that the cable meets all relevant technical standards, it also references supporting documentation that provides further interpretation and guidance on the necessary activities at every stage of deployment.

3 I3P inspection during cable fabrication

During fabrication, Independent Third Party (I3P) inspection includes documentation reviews and onsite inspections. These services are tailored and adjusted to meet the specific requirements or specifications of each project.

For the subsea power cable system, the key focus areas for these services include:

i) Documentation review
Review of fabrication records, certificates, specifications, procedures, test documentation, production worksheets, and more, including:

- ***a)*** Verification that the fabricator operates under a quality management system certified by an internationally recognized certification body (e.g. ISO 9001 or equivalent).
- ***b)*** Approved fabrication procedures, including test programs, corrosion protection, heat treatment and mechanical and electrical testing requirements
- ***c)*** Agreed Inspection and Test Plan (ITP) fabrication holds points.
- ***d)*** Welding procedure and personnel qualification records (according to ISO 9606-1 or equivalent).
- ***e)*** Welding inspection records.
- ***f)*** Equipment calibration records.
- ***g)*** Material certification and traceability records.
- ***h)*** Dimensional check records.
- ***i)*** Non-Destructive Test (NDT)/Non-Destructive Examination (NDE) records.

j) Records of completion

ii) Inspection
Inspection of cable fabrication to verify compliance with the approved documentation and specifications. This includes:

a) Verification of material traceability and certification

b) Inspection/witnessing of cable fabrication steps, such as the fabrication of power cores and power cables and their assembly with the termination, and confirmation that construction aligns with approved procedures and drawings.

c) Inspection/witnessing of welding, as applicable

d) Sample verification of examination and NDT/NDE in accordance with the approved procedures

e) Inspection/witnessing of corrosion protection system installation, as applicable

f) Inspection/witnessing of required prototype and production tests in accordance with the agreed ITP markup (or equivalent) and as per 4/7.1 including:

1) Type tests and range of type approval.

2) Routine tests.

3) Sample tests.

4) Prequalification test.

g) Witnessing FAT as per 4/11 is carried out in accordance with the applicable standards and purchaser requirements.

h) Sample inspection of any repair work, as applicable

5 I3P inspection during cable transportation and installation

During transportation and installation, I3P activities consist of documentation reviews and onsite inspection to confirm that the subsea power cable system and its associated components are transported and installed in accordance with the approved designs, the Transportation and Installation (T&I) plan, and the Inspection and Test Plans (ITP). The activities also verify that any loads experienced during these operations do not exceed the design envelope. In all cases, maximum environmental conditions, as well as the duration or persistence of limiting conditions, are to be specified and verified by documentation review.

The contractor responsible for the transport and installation tasks is to operate under a certified ISO 9001 quality management system or an equivalent. This certification provides a standardized framework for managing quality during transportation and installation operations.

5.1 I3P inspection during transportation

During the transportation phase, the following activities are carried out to verify that transport operations are carried out in accordance with T&I plan and ITP or equivalent (see 5/1.1 for more details):

i) Review of transportation records to verify compliance with the approved limits.

ii) I3P inspection: Inspection to confirm that transportation activities are executed in accordance with the approved transportation plans and ITP and that no visible damage has occurred.

5.3 I3P inspection during installation

During the installation phase, the following activities are carried out to verify that the key components of the installation process are executed in accordance with the approved installation plan and the ITP or equivalent (see 5/1.1 for additional details):

i) Documentation review: Review of installation documentation, including the installation plan, associated drawing, as applicable. Review of installation records to verify compliance with the approved limits.

ii) I3P inspection is to include, but not limited to, the following:

a) Confirmation that the completed installation aligns with installation plans and documentation of any deviations from the approved design.

b) Verification that all installation activities - such as cable laying, burial, crossings, free spans, interfaces, rock placement, and related works - are executed in accordance with installation plans, and the agreed ITP (as applicable), and approved designs.

7 I3P inspection during cable commissioning

During commissioning, I3P activities consist of documentation reviews and onsite inspection to confirm that the cable systems are commissioned in accordance with the relevant fabricator technical manuals, instructions, and approved documentation/procedures. This process confirms that the cable operates as intended, meeting the required operational and performance standards outlined in the approved documentation and commissioning procedures.

The I3P activities during commissioning are to, at a minimum, include the following:

i) I3P inspection/witnessing is to include, but is not limited, the following:

a) Verification that commissioning activities are carried out in accordance with the approved commissioning manual, and ITP (or equivalent).

b) Witnessing of key tests based on the mutually agreed scope defined in 6/3, including:

1) High voltage testing of the cable system (including terminations).

2) Optical time domain reflectometer (OTDR) testing.

c) Examination and review of commissioning records.

9 In-service I3P activities

In-service I3P activities include documentation review and verification that the specific subsea power cable system at a designated site is being operated and maintained in accordance with the relevant In-Service Inspection Plan (ISIP) or an equivalent framework. These activities involve a combination of documentation review and on-site inspections of the subsea power cable system. The detailed scope of these activities will be mutually agreed upon by the parties involved.

The I3P activities will include, but not limited to, the following key elements:

i) Documentation review:

a) Assessment of the status of outstanding findings from previous inspections that need to be addressed to maintain ongoing compliance.

b) Assessment of the status of outstanding recommendations from previous inspections that may require follow-up actions.

ii) I3P inspection:

a) Verification that in-service activities have been carried out in accordance with ISIP.

b) Inspection, if applicable, and verification that key repairs, remedial work, modifications and replacements have been executed in accordance with the operation and maintenance plan.

APPENDIX 1

Industry Code, Standards and Guidelines

- API RP 2A Recommended practice for planning, designing, and constructing fixed offshore platforms-working stress design.
- API RP 2EQ, Recommended practice for seismic design procedure and criteria for offshore structures.
- API RP 2ND Dynamic risers for floating production systems.
- API 17J Specification for unbonded flexible pipe.
- API RP 17B Recommended practice for flexible pipe.
- API 17L1 Specification for ancillary equipment for flexible pipe and subsea umbilical.
- API 17L2 Recommended Practice for Ancillary Equipment for Flexible Pipes and Subsea Umbilical.
- API RP 2MET, Recommended practice for derivation of metocean design and operating conditions.
- API RP 2GEO, Recommended practice for geotechnical and foundation design considerations.
- IEC 60183 Guide to the selection of high-voltage cables.
- IEC 60071-1 Insulation co-ordination- Part 1: Definitions, principles, and rules.
- IEC 60228 Conductors of insulated cables.
- IEC 60229 Electric cables - Tests on extruded over sheaths with a special protective function
- IEC 60287-1-1 Electric Cables-Calculation of the current rating-Part 1-1: Current rating equations (100% load factor) and calculation of losses-General.
- IEC 60287-2-1 Electric Cables-Calculation of the current rating-Part 2-1: Thermal Resistance-Calculation of thermal resistance.
- IEC 60287-3-2 Electric Cables-Calculation of the current rating-Part 3-2: Sections on operating conditions-Economic optimization of power cable size.
- IEC 60300-1 Dependability management-Part 1: Dependability management systems.
- IEC 60793 Optical fibers
- IEC 60794 Optical fiber cables
- IEC 60853-1 Calculation of the cyclic and emergency current rating of cables-Part 1: Cyclic rating factor for cables up to and including 18/30 (36) kV.
- IEC 60949 Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects.
- IEC 61400 series standards for offshore wind turbines

- IEC 61443 Short-circuit temperature limits of electric cables with rated voltages above 30kV (Um=36kV)
- IEC 82079-1 Preparation of information for use (instructions for use) of products.
- EN 13383-1 Armor stone-Part 1: Specification
- ISO 9001 Quality management systems-Requirements.
- ISO 9606-1 Qualification testing of welders.
- ISO 12473 General principles of cathodic protection in seawater.
- ISO 13623 Petroleum and natural gas industries-Pipeline transportation systems.
- ISO 13628-5 Petroleum and natural gas industries-Design and operation of subsea production systems-Part 5: Subsea umbilical.
- ISO 14688-1 Geotechnical investigation and testing-Identification and classification of soil-Part 1: Identification and description.
- ISO 14688-2 Geotechnical investigation and testing-Identification and classification of soil-Part 2: Principles for a classification.
- ISO 19901-6 Petroleum and natural gas industries-Specific requirements for offshore structures-Part 6: Marine operations.
- ISO 22475-1 Geotechnical investigation and testing-Sampling methods and groundwater measurements-Part 1: Technical principles for execution.
- ISO 31000 Risk Management Principles and guidelines.
- ISO 31010 Risk Management-Risk assessment techniques.
- ISO 55000 Asset Management-Overview, principles, and terminology.
- ITU-T G.976 Test methods applicable to optical fiber submarine cable systems
- ITU-T G.652, Characteristics of a single-mode optical fiber cable
- ITU-T G.654, Characteristics of a cut-off shifted single-mode optical fiber cable
- NORSOK G-001 Marine soil investigation.
- CIGRÉ B4 DC grid test system.
- CIGRÉ TB 177 Accessories for HV cables with extruded insulation.
- CIGRÉ TB 194 Construction, laying and installation techniques for extruded and self-contained fluid filled cable systems.
- CIGRÉ TB 279 Maintenance for HV cables and accessories.
- CIGRÉ TB 303 Revision of qualification procedures for HV and EHV AC extruded underground cable systems.
- CIGRÉ TB 346 Protocol for reporting the operational performance of HVDC Transmission Systems.
- CIGRÉ TB 379 Update of service experience of HV underground and submarine cable systems.
- CIGRÉ TB 398 Third-party damage to underground and submarine cables.
- CIGRÉ TB 415 Test procedures for HV transition joints for rated voltages 30 kV (Um=36kV) up to 500kV (Um=550kV).
- CIGRÉ TB 476 Cable accessory workmanship on extruded high voltage cables.
- CIGRÉ TB 483 Guidelines for the design and construction of AC offshore substations for wind power plants.
- CIGRÉ TB 560 Guideline to maintaining the integrity of XLPX cable accessories.

- CIGRÉ TB 610 Offshore generation cable connections.
- CIGRÉ TB 623 Recommendations for mechanical testing of submarine cables.
- CIGRÉ TB 722 Additional testing of submarine power cables from 6kV up to 60kV.
- CIGRÉ TB 862 Recommendations for mechanical testing of submarine cables for dynamic applications.
- CIGRÉ TB 880 Power cable rating examples for calculation tool verification.
- CIGRÉ TB 883 Installation of submarine power cables.
- CIGRÉ Electra 171 Recommendations for mechanical tests on sub-marine cables.
- CIGRÉ Electra 189 Recommendations for tests of power transmission DC cables for a rated voltage up to 800kV.
- CIRIA Guideline C683 The rock manual-the use of rock in hydraulic engineering.
- CIGRÉ Guideline C685 Beach management manual.
- Carbon Trust CTC 835 Cable burial risk assessment methodology: Guidance for the preparation of cable burial depth of lowering specification and associated application guide for the specification of depth of lowering.
- ICPC Recommendation 1 Management of redundant and out-of-service cables.
- ICPC Recommendation 2 Recommended routing and reporting criteria for cables in proximity to others.
- ICPC Recommendation 3 Criteria to be applied to proposed crossings between submarine telecommunications cables and pipelines/power cables.
- ICPC Recommendation 6 Recommended actions for effective cable protection (post installation).
- ICPC Recommendation 9 Minimum technical requirements for a desktop study (also known as cable desktop route study).
- ICPC Recommendation 11 Standardization of electronic formatting of route position.
- ICPC Recommendation 13 Proximity of wind farm developments & submarine cables.
- IMCA D 014 International code of practice for offshore diving.
- IMCA D 042 (R 016) Driver and ROV based concrete mattress handling, deployment, installation, repositioning, and decommissioning.
- IMO MSC.1 /Circ. 1580 Guidelines for vessels and units with dynamic positioning (DP) systems.

APPENDIX 2
Cable Storage

The proper storage of subsea power cables is important to maintaining their integrity and performance until they load out. Storage conditions are to be defined by the cable fabricator and take into account the risk of cable damage. The minimum storage requirements are to include the following considerations:

i) Environmental conditions

a) Storage temperature and humidity are to be specified and confirmed by the cable fabricator.

b) Cables stored outdoors are to be shielded from direct sunlight and UV radiation.

c) Cables are to be protected from rain, snow, and other adverse weather, by waterproof covers, storage shelters, or other suitable means.

d) Cables are to be handled and stored away from chemicals, oils, and substances that could cause damage.

ii) Physical protection

a) Cables is to be stored on suitable drums, reels, carousel, turntable, or coiled into a storage tank or pads to prevent kinks and crushing. Protective coverings are to be used where necessary.

b) Only cables specified as "coilable" may be coiled, and the fabricator's minimum coiling diameter is to be followed.

c) Stacking cable drums is to be avoided unless the drums are designed for stacking and the load does not exceed drum strength.

d) Cables are to be kept away from sharp edges and rough surfaces.

e) Cables are to not be bent to below their minimum bend radius.

f) Electrical core and optical cables are to be capped and sealed to prevent water ingress.

g) Reel diameter is to accommodate end-termination dimensions and any required bend stiffener/limiters.

h) Cables are to be spooled onto storage reels or shipping/installation reels with controlled back-tension to prevent loose turns during removal.

iii) Support and handling

a) Cable drums are to provide adequate support and have suitable lifting points for proper handling during transportation and installation.

b) Cable drums are to be moved in accordance with the cable fabricator's instructions using handling equipment that is suitable for the drum size, weight, and structural integrity.

iv) Positioning and layout

- *a)* Drums are to be stored horizontally on a stable, flat surface.
- *b)* Drum flanges are to be supported to prevent deformation of the cable.

v) Long-term storage considerations

- *a)* Cables are to be inspected regularly for damage, moisture, or other issues, any findings are to be promptly addressed.
- *b)* The cable fabricator is to specify maximum storage duration for the selected storage method.
- *c)* For spare cables, shelf-life and periodic replacement requirements are to be documented and reported.

vi) Documentation

- *a)* Record cable details such as cable type, serial number (as applicable), and storage location.
- *b)* Document the cable's condition at the time of storage and maintain periodic inspection logs.
- *c)* Maintain a handling log that includes the date, location, and handling notes for each cable.
- *d)* Record storage temperature and humidity levels for reference.
- *e)* Record total storage time and the maximum allowable storage duration for each cable.