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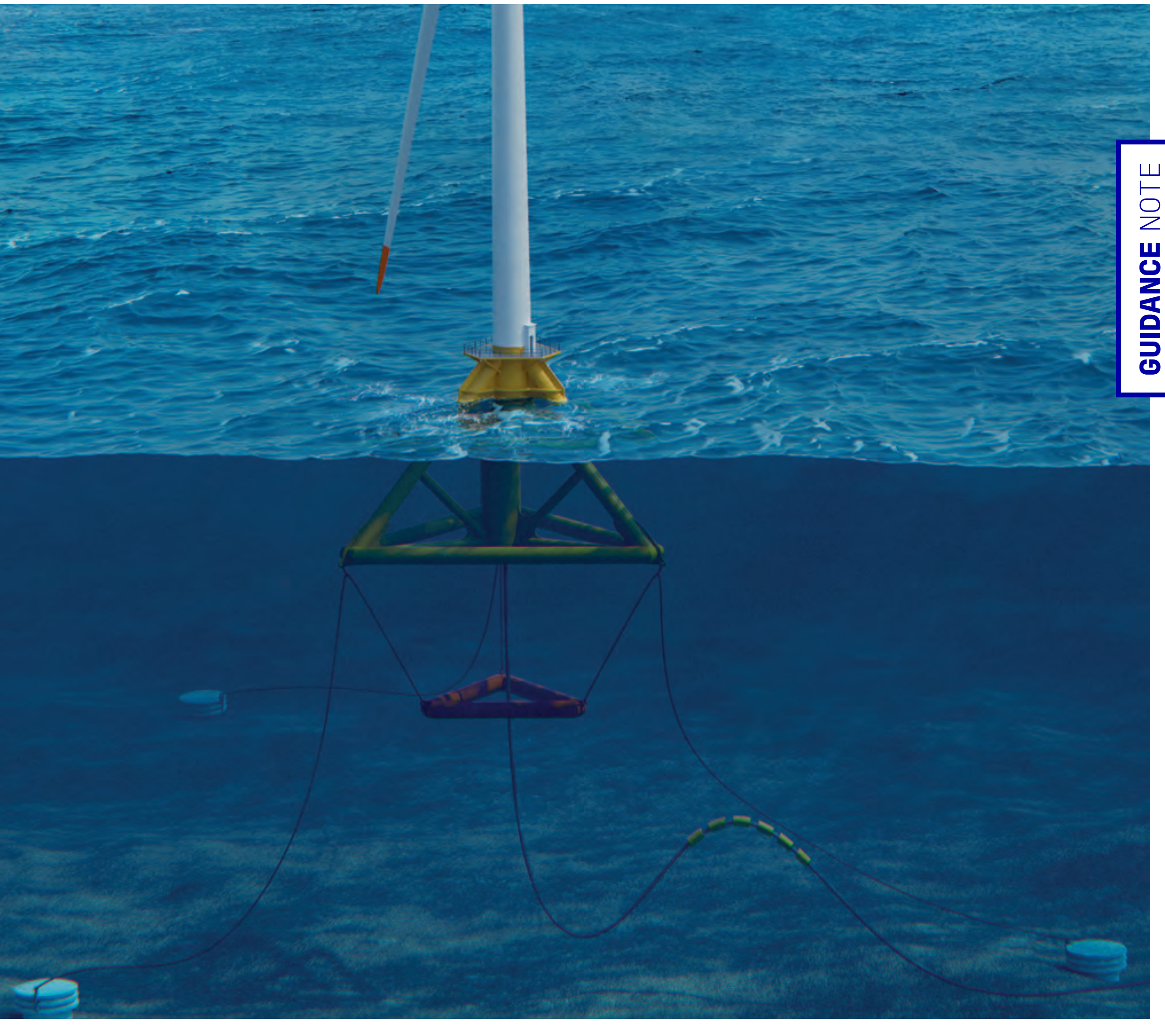
VERIFICATION SCHEME FOR DYNAMIC SUBSEA POWER CABLE

NI685 - SEPTEMBER 2024



GUIDANCE NOTE

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September 2024

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Section 1 General

1 Scope

1.1 Application

1.1.1 General

This Guidance Note describes the Society verification scheme for dynamic subsea power cable and associated ancillary items for Floating Offshore Wind Turbines (FOWT), Marine Renewable Energy (MRE) and offshore applications.

This Guidance Note does not apply to umbilicals, flexible pipes and telecommunication cables.

1.1.2 Objectives

In the recent years, wind industry has started developing floating offshore wind farms.

The dynamic subsea power cables, transmitting electrical power from the FOWT to the grid are submitted to severe environment and operational loads, and consequence of a failure of these products make them critical for developers and operators.

The qualification of a dynamic subsea power cable for a given project may require extensive qualification testing activities which may be partially reduced depending on the robustness of the design methodologies developed by the cable manufacturer.

Similar situation has been experienced by the flexible pipe industry several years ago and has led to the issuance of the API 17J, requiring type approval certification of manufacturer design methodologies. BV has later on issued the Guidance Note NI364 to describe its verification scheme for flexible pipe, which has supported the development of this Guidance Note.

The objective of this Note is to present BV requirements for the certification of dynamic subsea power cable on a given project. The requirements for the certification of design methodologies, directly handled by the cable manufacturer and aiming at reducing qualification testing activities on a given project, are also presented.

1.1.3 Perimeter

The subsea power cables considered in this Note are to be designed for applications such as floating wind turbines or other applications needing subsea dynamic power cable for instance Floating Production Storage and Offloading units and are to be with the following characteristics:

- Alternating Current (AC) Dynamic Subsea Power Cables (Inter Array and Export)
- rated voltage U from 6kV to 66kV.

This Guidance Note may also be applied to the qualification and verification of static cable.

The main principles set forth in this Guidance Note may also be applied to the qualification and verification of cable with rated voltage higher than 66kV.

Note 1: Rated voltage U is defined in IEC 60183:2015.

1.1.4 Technical requirements

At the time of issuance of this Guidance Note, no internationally recognized standard specific to dynamic subsea power cable and covering its entirety is available. Applicable technical requirements and recommendation on design criterion for certification of subsea dynamic power cables are given in this Guidance Note.

Different cable design and construction may be used to achieve power transmission. In particular, wet design cable and cable with water barrier may be proposed

For qualification of such cables, the verification activities are supported by the main standards and guidelines:

- IEC 63026:2019
- ISO 13628-5:2009
- CIGRE TB 722:2020
- CIGRE TB 862:2022.

Other supporting codes and recommended practices are listed in Article [3].

Note 1: TB 722 gives the methodology to establish if a design is dry or not.

2 Definitions and acronyms

2.1 Definitions

2.1.1 General

The following terminology is used in the present document.

2.1.2 Capacity curve

Curve that defines the relationship between the allowable bend radius and allowable mechanical tension.

2.1.3 Component

Collection of sub-components which when brought together function as a unit (e.g. power cores).

2.1.4 Conformity statement

Document issued by an Independent Verification Agent (IVA) within the context of a commercial project, certifying that specified requirements related to a dynamic power cable has been fulfilled. Design, manufacturing, and installation phases are relevant.

2.1.5 Design methodology verification report

Evaluation report prepared by an Independent Verification Agent (IVA) at the time of an initial review, for a specific Manufacturer, confirming the suitability and appropriate limits on the Manufacturer's design methodologies, manufacturing processes, and materials. This report may include occasional amendments or revisions to address extensions beyond previous limits or revisions of methodologies.

2.1.6 Dry/wet design

Category of cable depending on radial water blocking capability of insulation layer. Cable design identification is described in CIGRE TB 722:2020 [3.4].

2.1.7 Environmental conditions

Internal, external and operational conditions to which the system is exposed, including physical, chemical, biological and usage conditions (i.e. seawater environment, water depth, seabed conditions, temperature, marine growth, etc.).

2.1.8 Evaluation report

A report including the results of conformity assessment. The report is the basis for the decision to issue the conformity statement and should enable the receiver of the statement to understand the extent of the certification, and list information that is required for certification of modules to which the certificate interfaces.

2.1.9 Export cable

The export cable connects the offshore and onshore substations to transmit power from the power plant (e.g. wind farm) to shore.

2.1.10 Factory joint

Joint between power core insulation extrusion lengths that is manufactured under controlled factory conditions.

2.1.11 Failure mode

Effect by which a failure is observed on the failed item (i.e. the loss of a required functionality, e.g. loss of electrical power transmission).

2.1.12 IEC type test

Conformity tests related to IEC standard made on one power cable representative of the production.

2.1.13 Inter-array cable

Subsea power cable connecting two MRE units (i.e. FOWT) or a MRE unit (i.e. FOWT) and an offshore substation.

2.1.14 Inter-array cable system

System including the Inter Array Cable, its terminations (electrical and mechanical) together with the associated ancillary items (bend stiffener, bend restrictor, tether clamp system…).

2.1.15 Limit state

State beyond which an item no longer satisfies the requirements. The following categories of limit states are of relevance for structures design:

ULS : Ultimate Limit State

FLS : Fatigue Limit State

ALS : Accidental Limit State.

2.1.16 Manufacturer

Power cable manufacturer.

Some power cable manufacturers manufacture their own power core. Other power cable manufacturers purchase the power cores at power core supplier and perform the overall assembly of the cable.

2.1.17 Prototype
Trial product produced to test a concept or process.

2.1.18 Prototype test
Test to establish or verify a principal performance characteristic for a particular power cable design, which may be a new or established design, and to also validate Manufacturer design methodology and so provide a basis for the Third-Party verification. Not to be confused with IEC type test.

2.1.19 Power cable
Assembly of power cores which includes terminations. Refer to Sec 4.

2.1.20 Power core
One phase cable.

2.1.21 Purchaser
Purchaser of a power cable.

2.1.22 Qualification
Process of confirming, by examination and provision of evidence, that equipment meets specified requirements for the intended use, the combination of Verification and Validation activities.

2.1.23 Q-FMECA
Integrated FMECA (Qualification Failure Mode Effects and Criticality Analysis) with the purpose of identifying and prioritizing qualification activities for a technology.

2.1.24 Qualification testing
Testing by which the structural, functional, fabrication, and reliability performance of a power cable design, its components, or materials used may be evaluated in order to demonstrate suitability for the specified service life in a specific application. Qualification testing can also be used to validate the Manufacturer's design methodology for a new power cable design.

2.1.25 Quality assurance (QA)
Planned, systematic, and preventive actions that are required to ensure that materials, products, or services meet specified requirements.

2.1.26 Quality control (QC)
Inspection, test, or examination to ensure that materials, products, or services conform to specified requirements.

2.1.27 Range of applicability
It defines the range of use specified by users complemented by the characteristics of the qualified envelop / extent of evidence provided for qualification.

2.1.28 Range of use
Range of operating conditions for which the power cable is specified by users (for example group voltage, electrical power transmitted, external pressure, etc.).

2.1.29 Specification
Document in which function, performance, design and operating requirements are defined, together with associated reliability and integrity goals and requirements.

2.1.30 Supplier
Power cable manufacturer's supplier.

2.1.31 System
Electrical power conveyance system, connected to farm equipment in both extremities, in operation or ready to operate, for which the subsea power cable is the primary component and includes ancillary components and accessories attached directly or indirectly to the power cable.

2.1.32 Technology
Component, a product, a physical process, or system used to perform specific functions and/or to achieve specific goals.

2.1.33 Technology Qualification Program (TQP)
Qualification program that utilizes a Q-FMECA to identify qualification activities necessary to qualify the technology in line with the identified goals and requirements.

2.1.34 Test scale
Tests can be performed at different scale (small scale for material testing, middle scale for component testing or full scale for cable testing).

2.1.35 Third party

Independent party or group, selected by the Manufacturer or the Purchaser, who is responsible for the review and certification of an indicated product (power cable system, design methodology), based on testings, technical literature analysis, results, and other information provided by the Manufacturer to establish the range of applicability. Witness measurements and control tests related to material qualification or product manufacturing.

2.1.36 Type approval certificate

When several design methodology verification reports and associated certificates have been issued to a Manufacturer, they may be gathered into a Type Approval Certificate to add consistency to the verification of the cable technology. Type Approval definition is in line with API 17J standard.

2.1.37 Type approval certification

Independent review and certification by a Third Party of the indicated product concept (e.g. subsea power cable and termination concept) and subsea power cable associated design, manufacturing methodologies and criteria, material qualification and prototype performance based on the technical literature, analyses, results, and other information provided by the Manufacturer to establish the range of applicability.

2.1.38 Uncertainty

State of having limited knowledge where it is impossible to exactly describe the existing state or future outcome(s).

2.1.39 Validation

Confirmation, by testing, that the requirements for a specific intended use or application have been fulfilled. The confirmation can comprise activities such as (list is not all-inclusive): Prototype testing, functional and/or operational testing of production products, testing specified by industry standards and/or regulatory requirements, field performance testing and reviews.

2.1.40 Verification

Confirmation, through provision of objective evidence, that specified requirements have been fulfilled. The confirmation can include activities such as (list is not all-inclusive): performing alternative calculations, comparing a new design specification with a similar proven design specification, undertaking investigative tests and demonstrations, reviewing design output documents against specified requirements.

2.2 Acronyms

2.2.1

AC : Alternating Current
BV : Bureau Veritas
CIGRE : Conseil International des Grands Réseaux Electriques
COC : Certificate of Conformity
EPR : Ethyl Propyl Rubber
FAT : Factory Acceptance Test
FOWT : Floating Offshore Wind Turbine
IAC : Inter-Array Cable
IEC : International Electrotechnical Commission
IRC : Independent Design Review Certificate
ITP : Inspection and Test Plan
IVA : Independent Verification Agent
MRE : Marine Renewable Energy
NDT : Non-Destructive Testing
OSS : Offshore substation
QA/QC : Quality Assurance / Quality Control
RMS : Root Mean Square
TAC : Type Approval Certificate
TQP : Technology Qualification Program
WTG : Wind Turbine Generator
XLPE : Cross linked Polyethylene.

3 References

3.1 Society documents

3.1.1 Guidance Note NI364 Verification Scheme for Unbonded Flexible Pipes.

3.1.2 Guidance Note NI525 Risk Based Qualification of New Technology - Methodological Guidelines.

3.2 IEC documents

3.2.1 IEC 63026:2019 Submarine power cables with extruded insulation and their accessories for rated voltages from 6 kV (Um = 7,2 kV) up to 60 kV (Um = 72,5 kV) - Test methods and requirements - Edition 1.0.

3.2.2 IEC 60840:2020 Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) - Test methods and requirements - Edition 5.0.

3.3 CIGRE documents

3.3.1 CIGRE TB 623:2015 Recommendations for mechanical testing of submarine cables.

3.3.2 CIGRE TB 722:2020 Additional testing of submarine power cables from 6kV up to 60kV.

3.3.3 CIGRE TB 862:2022 Recommendations for mechanical testing of submarine cables for dynamic applications.

3.3.4 CIGRE TB 490 Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to 500(550) kV.

3.3.5 Cigre TB 610 Offshore Generation Cable Connections.

3.4 ISO documents

3.4.1 ISO 13628-5:2009 Design and operation of subsea production systems - Part 5: Subsea Umbilicals.

3.4.2 ISO 9001:2015 Quality management systems, requirements.

3.5 API documents

3.5.1 API Specification 17E Fifth Edition - Specification for subsea umbilicals, January 2017.

3.5.2 API Specification 17J Fifth Edition - Specification for Unbonded Flexible Pipe, June 2024.

3.5.3 API RP 17B Sixth Edition - Recommended Practice for Flexible Pipe, May 2014.

3.5.4 API Specification 17L1 Specification for Ancillary Equipment for Flexible Pipes and Subsea Umbilical, June 2021.

3.5.5 API Specification 17L2 Recommended Practice for Flexible Pipe Ancillary Equipment for Flexible Pipes and Subsea Umbilicals; Second Edition, June 2021.

3.6 Other documents

3.6.1 DNV RP F109. On-bottom stability design of submarine pipelines.

4 Dynamic subsea power cable description

4.1 General

4.1.1 Dynamic subsea power cables are used to connect two electrical units, one at least being floating (floating wind turbine, offshore platform, wave energy convertor etc.).

4.2 Cross section arrangement

4.2.1 Dynamic subsea power cables are complex products, consisting of an assembly of multiple metallic and polymeric layers, submitted to severe loadings in terms of service conditions, electrical power transmitted and mechanical loadings. Cable cross sections are therefore specific to each manufacturer and project.

4.2.2 Typical arrangement

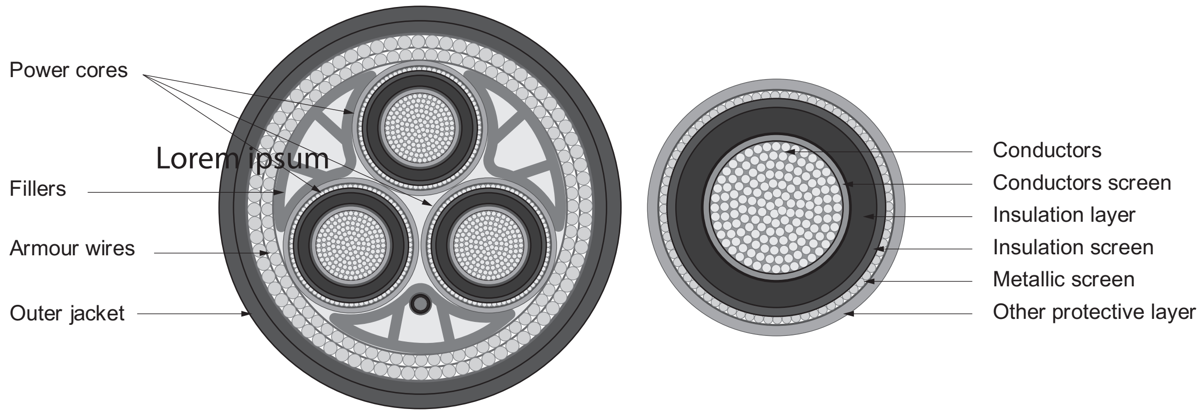
The typical arrangement of an AC subsea power cable, taken as example, as well as the basic function of each layer is recalled hereafter. The power cores are at the core of the power cable and ensure the electrical functions. Then, a lay-up is in general applied to ensure mechanical properties of the cable. Laying of the power cores is in general performed helically (or SZ method) to allow bending flexibility of the overall assembly. Some cable manufacturers may procure the power cores from external suppliers. Fig 1 presents the typical arrangement of such power cable, composed of the following layers and components:

a) Power cores, typically made of the following items:
   - Conductors, which are made of copper or aluminium and aim at transmitting the electrical power.
   - Insulation system, which consists of three layers: conductor screen, insulation layer, insulation screen. The insulation layer can be made of Ethyl Propyl Rubber (EPR) or Cross Linked Poly Ethylene (XLPE), it provides an electrical barrier between the main current carrying components of the cable.
   - Metallic screen, made of copper or aluminium tapes or wires, act as return path for short circuit current and capacitive current.
   - Radial water barrier (if relevant), to prevent or significantly diminish ingress of water into the cable insulation.
   - Power core outer protective layer may be installed to protect power cores from mechanical damage.

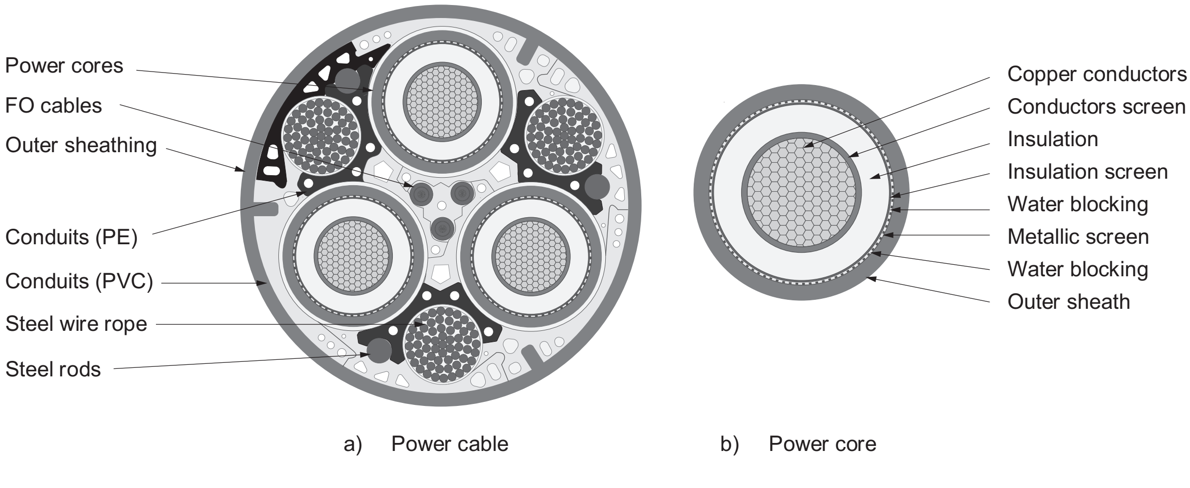
b) Power cable lay-up, typically made of the following items:
   - Fillers, extruded or made of ropes, are used to keep the overall construction as round as possible. Fiber optic cables are usually inserted for data exchange and/or monitoring (temperature, acoustic, strain) during cable operation.
   - Internal sheath beneath armour to keep the cylindrical shape.
   - Armour wires, applied helically in one or more layers are used for tensile strength and mechanical protection.
   - Outer jacket is used as abrasion protection and contributes to the bending stiffness of the cable.

   Other cross section arrangements are recognized in the industry and include extruded profiles that fully encompass each individual sub-component and utilize metallic or non-metallic strength elements in the interstices of the cross section in-lieu of a separate armor layer. This cross section type, or any other arrangement that satisfies functional requirements may be proposed by cable manufacturers. Other layers may also be added, for specific functionalities (e.g. intermediate sheath to provide additional bending stiffness).

Figure 1 : Illustration of typical arrangement of a dynamic power cable and a power core



a) Power cable   b) Power core



a) Power cable   b) Power core

4.3 Terminations

4.3.1 Mechanical termination (for termination of load carrying elements) location may differ from electrical termination (power cores).

In the WTG and at Offshore Substation, power cores are generally terminated using a plug-in arrangement directly connected into the WTG/OSS switchboard or junction. The anchoring system (called the hang off) of the armour wires or other strengths members allows the transfer of the mechanical loads to the supporting structure (e.g. specific armour geometry, resin…).

4.4 Joints

4.4.1 Joints are usually inserted on power cables due to required length that can exceed production capacities of power cable factories. Joints are not allowed in dynamic section of the power cable. Two families of joints can be distinguished, flexible joints and rigid joints:

- Flexible joints are done to assemble two lengths of cable, and final properties (electrical, dimensional, mechanical) are similar to original cable. Among the flexible joint family, the factory joints are performed to assemble two lengths of power cores together, during lay-up. The conductors are connected by ferule and the insulation layers are reconstructed, with tapes of the same insulation material or by extruding a virgin insulation material in a mold, followed by curing.
- Rigid joints are joints made of prefabricated elements. Once the power core joints are completed, the power core bundles are generally placed in a metallic cylinder where the cable armouring is firmly secured. Bend restrictors or bend stiffeners are often installed at each end of the metallic cylinder to avoid over bending of the cable during the deployment of the rigid joint.
- Welds may also be present on other cable components (typically butt welds on steel wires).

4.5 Cable general configuration

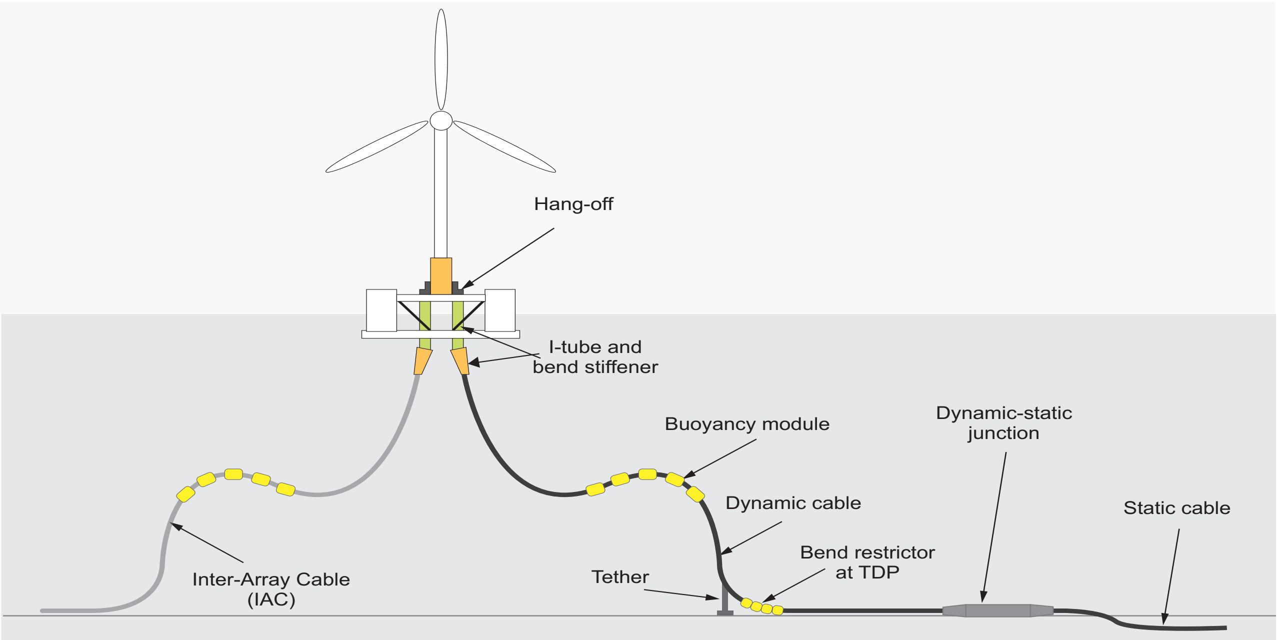
4.5.1 Different configuration may be used for dynamic subsea cable system, depending on project conditions. In general, the dynamic power cable system extends from the floating structure attachment point to the seabed.

The different configurations are detailed in CIGRE TB 862 and API17B. Ancillary items are detailed in API17L1&L2.

The different components and accessories that may be used (depending on the targeted configuration) on a dynamic power cable system for a single offshore floating unit are illustrated in Fig 2 and detailed here below:

- bend stiffener or bell mouth at the floating structure attachment point
- buoyancy modules
- tether with clamp and anchoring system
- protection jackets
- ballast collars
- bend restrictors.

Figure 2 : Dynamic power cable configuration and accessories



5 Verification scheme for dynamic subsea power cable

5.1 Product verification specificities

5.1.1 Cable verification specificity

The verification of dynamic subsea power cable is a complex task, due to the following specificities:

- The geometries and materials of the metallic and non-metallic components of the cable are specific to each manufacturer and so is the general design philosophy of power cable cross-sections and termination.
- The fabrication process and control methods are specific to each manufacturer. The power cores are products for which the final performances are closely linked to the power core manufacturing. Power cable cross section arrangement may vary between manufacturers and cable final performances are also closely linked to manufacturing process of the power cable.
- The power cables are not off-the-shelf products but are generally customized according to the external and operational conditions (e.g. static/dynamic, water depth) and their required functions (electrical power to transmit).
- The subsea power cable industry is a competitive industry, implying that significant R&D work is carried out in order to improve competitiveness of the power cables and the suitability to harsh conditions. This entails a strong need for confidentiality of the quickly evolving technologies used.
- The power cable is a complex product in itself due to its composite multi-layer nature and its design requires addressing many failure modes and fields of expertise.

5.1.2 Certification approach

These specificities entail some consequences regarding the certification strategy and timeline for dynamic subsea power cables qualification:

- The evolving, confidential, manufacturer's specific designs cannot be addressed in detail in common normative document. Requirements defined in this Note and in the referenced standards have set prescriptive requirements and criteria for some design and material aspects together with some goal setting stipulations in order to fit with these product specificities.
- The qualification and model validation by testing is frequently required due to the complexity of the tailor-made subsea power cable products.
- The significant testing costs and potential number of tests to be performed to qualify and certify a dynamic subsea power cable from scratch may be prohibitive in a project context. It is therefore recommended to perform upstream technology certification activities (see [5.3]) before project certification.

5.2 Project certification

5.2.1 General

The project certification refers to the certification of a specific cable system for a specific application. To this end, a Purchaser has established specifications to define operating requirements and has issued an order to a Manufacturer. The certification is dedicated to the verification of a specific cable design, manufacturing and installation for a site-specific power plant.

5.2.2 Project certification process

In a project -related phase, the Society is to be contracted to perform the following activities:

- The cable system design proposed for the project is investigated versus end user specification. In particular, qualification evidences brought by the manufacturer are examined.

  The deliverable is a Design Evaluation Conformity Statement.
- Manufacturing surveillance: surveys are performed during the actual fabrication, control and testing of the subsea power cable, to assess conformity of power cable manufacturing versus design assumptions and end user spec.

  The deliverable is a Manufacturing Conformity Statement.

If some of the design methodologies of the subsea power cable manufacturer are covered by an Independent Verification Agent (IVA) certificate, the timeframe of the project is significantly reduced by avoiding to re-examine the technology related aspects for each project. If the design methodologies are not approved, the corresponding activities are performed in the project certification, which implies longer review time.

In addition, the Society may be contracted by the manufacturer at an early phase of the project (FEED phase) to assess the suitability of an initial cable design and configuration before the cable manufacturer is contracted by the purchaser.

The project certification work is detailed in Section 2.

5.3 Material and design methodology certification

5.3.1 In order to streamline the project certification process, the Society's approach is to take advantage of an upstream work carried out in cooperation with the subsea power cable manufacturer.

The objective is to examine the design methodologies and define a range of applicability for each of them.

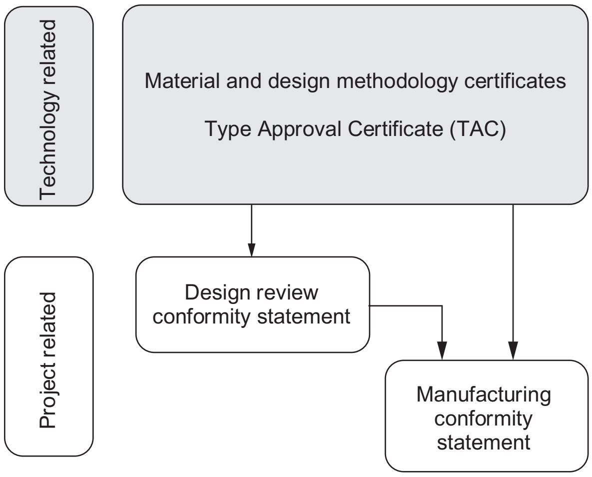
This upstream work related to the technology is called Type Approval work and leads to design methodology, material and manufacturing process verification certificates. Material qualification may also be part of this Type Approval assessment work.

The various technology verification certificates may eventually be combined in the Type Approval Certificate (TAC).

Type Approval certification work is a common practice for subsea equipment such as Flexible pipes and umbilicals. Type Approval Concept is defined in standards related to these equipment.

The Type Approval certification work is detailed in Sec 3.

Figure 3 : TAC



5.4 Operational management

5.4.1 The End user is expected to operate and monitor the power cable system in accordance with project design basis and monitoring and maintenance plan, allowing to follow the product condition. Following an incident during operation or at the end of the power cable lifecycle, a re-assessment may be performed in order to certify that the system can still be operated with expected performance and safety requirements and in accordance with end-user requirements.

The Operational management is detailed in Sec 4.

5.5 Qualification of new technology

5.5.1 As the subsea power cable industry is a competitive industry with challenging applications, it is a common practice for manufacturers to develop new technologies, either related to the cable design, design methodologies, materials, or manufacturing methods.

A technology qualification can be performed for this purpose. The technology qualification is based on a Qualification Program aiming at proving the suitability of this new technology.

The Qualification Program is based on a Q-FMECA (Qualification Failure Mode Effects and Criticality Analysis). It identifies the risks and uncertainties potentially brought by the new technology and concludes on the content of the Qualification Program required to remove the uncertainties and make the risks manageable. A Q-FMECA will provide details regarding threats and weaknesses, which should be used to define testing or analysis activities in order to demonstrate the ability of the subsea power cable system embodying the new technology to meet specified requirements.

As a general rule, the final certificate and technical report associated to the qualification of a new technology is intended for consolidation within the Type Approval process 5.3.

Examples of new technologies, or of events when the Q-FMECA process can be considered include:

- the extension of a qualified range or enhancement of a qualified technology (design methodology, material, manufacturing capability, power cable design) to an unqualified domain or application
- the development of a design methodology for a new failure mode
- the development of a new design concepts
- the development of a new material
- the development of a new layer
- the development of a new manufacturing method
- the qualification of a new material or component supplier.

The Society procedure for assessment of new technology qualification is described in App 1.

5.6 Summary of verification services

5.6.1 The list of verification services for dynamic subsea power cable is given below and summarized in Tab 1:

- Project Certification:

  During the design phase of a project, the Society may be contracted by the Purchaser or the Manufacturer in order to assess the subsea power cable system design and manufacturing with regards to the End-user's specifications. The deliverables are a design evaluation conformity statement covering the design conformity aspects as well as a Manufacturing conformity statement covering the final conformity of design and manufacturing aspects with its ancillary items. For additional information, refer to [5.2] and Sec 2.
- Material & Design Methodology Certification:

  For the technology-related aspects of its products, a Manufacturer can request a Type Approval Certification. The deliverables are Design Methodology certificates and material certificates which are aimed at being regularly updated within the Type-Approval process. For additional information, refer to [5.3] and Sec 3.
- Operational management:

  In case of an incident during the operation of the power cable or at the end of its initial lifetime, the Owner of the power cable system may request a Third-Party review to the Society in order to state that its power cable system still meets performance and safety requirements. The deliverable is a Certificate of fitness for service or of lifetime extension. For additional information refer to [5.4] and Sec 4.
- Qualification of New Technology:

  When a Manufacturer develops a new technology, the Society may assess the qualification program as well as its implementation and issue a Certificate of New Technology Qualification. For additional information, refer to [5.4] and App 1.

Table 1 : Overview of verification activities

Product phase	Type of service	Type contractor	Society's deliverable
Technology qualification and certification	Qualification of new technology	Manufacturer	Certificate of New Technology qualification
	Type approval certification	Manufacturer	Material and Design Methodology certificates
Project	FEED certification	Project Developer	Basic design conformity statement/Status Letter
Project	Project certification	Project Developer Purchaser	Design evaluation conformity statement Manufacturing conformity statement Installation conformity statement
Operation	Operational management	Owner operator	Certificate of fitness for service Certificate of life extension

Section 2 Project Certification

1 General

1.1 Application

1.1.1 This Section describes the Society verification scheme associated to subsea dynamic power cable system on a site-specific project.

The project certification refers to the certification of a specific cable system for a specific application. To this end, a Purchaser has established specifications to define operating requirements and has issued an order to a Manufacturer.

The project certification shall ensure that the cable system (including ancillary items) meets the applicable requirements.

1.2 Project certification process

1.2.1 As the power cable design and manufacturing are not necessarily carried out nor verified by the same entities and according to the same schedules, it is convenient to split the project certification into three parts:

- an initial gap analysis, to identify non-qualified or non-Type-Approved items at an early stage
- a certification of the design aspects, called Design Evaluation Conformity Statement, which covers the verification of cable design and its associated qualification activities (including material selection)
- a certification of the manufacturing and factory acceptance testing of the products, called Manufacturing Conformity Statement.

In this Section, the various verification activities proposed by the Society are described. Depending on its own needs, the Purchaser may request a partial scope of verification.

1.3 FEED certification

1.3.1 The Society may be contracted at early stage of a project (FEED), before an order is issued to a Manufacturer.
At the FEED stage of a project, preliminary cable design data are taken into account to perform feasibility analysis and verify suitability of a chosen cable configuration. Some key cable inputs are in general missing, as they are proprietary and specific to each cable manufacturer. For each analysis, the list of assumptions, acceptance criteria and results submitted to the Society are scrutinized. It is expected that the cable specifications to be addressed to cable suppliers are established at the end of the FEED phase. These specifications are to be submitted to the Society for review. The deliverable is a basic conformity statement or a status letter.

2 Gap analysis

2.1 General

2.1.1 Time schedule

Once an order has been issued to a manufacturer and the Society is contracted, the first step of review is an early gap analysis between qualification activities needed for the project and qualification activities already performed by the Manufacturer.

As this review step can impact the overall project schedule and costs due to supplementary qualification requirements, it is recommended to involve the Society as early as possible, and it is recommended that the manufacturer applies for Type Approval certification of his design methodologies.

2.2 Design basis

2.2.1 As a first step of the project certification process, a design basis including codes, standards, and client requirements to be followed is to be provided to the Society.

A general description of the project and of the power cable system is also to be submitted as part of the design basis. In particular, the power cable voltage rating, U_0, U and U_m, as defined in IEC 60183:2015, and the classification of insulation layer (wet design or dry design) are to be provided.

2.3 Verification of IEC type approved range

2.3.1 General

The IEC 63026:2019 specifies test methods and requirements including electrical and mechanical tests to be performed on a power cable sample from the manufacturer to qualify its design for static application. Once the tests have been performed, there is no need for the cable manufacturer to repeat the tests on the proposed cable design for the project, provided that it falls within the Type Test range defined in IEC 63026:2019 [12.2].

2.3.2 Verification of Type Approved Range

As a prerequisite, the scrutinized power cable is to be covered by the Type Approved Range from IEC 63026:2019. Accessories such as flexible and rigid joints proposed for the project are also to be covered by IEC 63026:2019.

2.3.3 Particular points of attention

As per condition IEC 63026:2019 12.2 c) of type test range, insulation and semi conducting screens for proposed cable and accessories are to be of the same type and manufacturing process than those from the tested cable. Details of material grades or material code of insulations layers are therefore to be provided. Details of manufacturing process is also to be documented, especially if the tested power cores and proposed power cores are not manufactured on the same manufacturing line or in the same factory.

2.3.4 As per condition IEC 63026:2019 12.2 h), the proposed cable system is to be subjected to the same or less severe mechanical stress (tension, bending, water pressure, etc.) than the tested cable. This condition is verified once engineering analysis (global, installation) have been performed, and may therefore not be validated at early design stage of the project.

2.4 Verification of insulation material qualification

2.4.1 For wet design power cable, the manufacturer has to present test reports (in particular wet ageing tests) associated to CIGRE TB 722:2020 and demonstrates that proposed cable design fall within the range of applicability of CIGRE TB 722:2020 (Table 3.2). If factory joints are included in the proposed power cable system and if they are of wet design, it is expected that factory joints are also qualified versus CIGRE TB 722:2020.

It is to be noted that the manufacturing process and grade of insulation material has a huge impact on wet ageing properties. The manufacturer has to demonstrate that the tested insulation material and proposed material for the project are identical.

2.4.2 For dry design power cable, the water barrier layer used shall be properly qualified. Watertightness of the barrier has to be demonstrated according to Cigre TB 446 and Cigre TB 490.

2.5 Verification of cable qualification

2.5.1 Dynamic application and fatigue tests

The main requirements for mechanical qualification of the cable system for dynamic application are presented in CIGRE TB 862:2022. In particular, a full-scale fatigue test of the power cable is to be performed to qualify it for dynamic application. If a full-scale fatigue test has been previously performed on a similar cable cross section, this may be sufficient to qualify the proposed power cable for the current project. In this case, it is to be demonstrated that the previously tested power cables and loadings conditions cover the current power cable design and project conditions with suitable safety margins. The range of validity for a previous full scale fatigue test is defined in CIGRE TB 862:2022, Table 6-3.

The methodology used to assess fatigue damage on project and during full scale fatigue test shall be consistent. The actual robustness of the methodology used to assess fatigue damage will be evaluated and shall respect Sec 3, [3.4].

Note 1: Component testing may also be an alternative for slight modifications between already tested cables and proposed cable for the project.

For each metallic component (conductors, screen wires, armour wires and metallic sheath for dry design cable) a safety factor of 10 between tested material and calculated fatigue damage for the project is to be met.

Learnings from full scale fatigue tests have shown that metallic screen is very sensitive to fatigue. Qualification testing evidence of this component shall therefore be particularly documented.

2.5.2 Consideration of third-party certificates

If one or several design methodologies of the manufacturer are covered by an Independent Verification Agent (IVA) certificate, the range of validity of the design methodology and the corresponding certificate including its annexes, if any, is to be submitted to the Society for review.

2.5.3 With all the information provided, the Society can perform an initial assessment of qualified and non-qualified aspects.

2.5.4 Q-FMECA

If non-qualified aspects emerge from the gap analysis, a Q-FMECA exercise as per App 1 is to be performed to determine if a mitigation plan is required or if the proposed design may be accepted as it is, based on limited utilization within the project conditions. Mitigation actions may include further project qualification work (e.g. additional studies, material testing, prototype testing), design assumptions refinement or design modification.

The objective is to determine at an early stage of the project:

- the tests that do not need to be executed due to sufficient justifications, documented track record or experimental evidence
- the qualification plan to be executed.

In case a qualification program is defined, its review procedure will be as specified in App 1. The outcome of the qualification activities may be considered for consolidation, extension and incorporation within the generic design methodology, material and manufacturing verification deliverables.

3 Design evaluation

3.1 General

3.1.1 The Design Evaluation Conformity Statement is the result of the satisfactory conformity assessment of the cable system design with regards to the requirements of applicable standards as well as the Purchaser's technical specifications.

3.2 Inputs

3.2.1 General

The power cable system design including all project assumptions is to be provided together with project specifications. In particular, the following (if applicable) is to be described:

- MRE units and subsea cables layout: Number of MRE units and general cable routes
- project specific conditions: metocean condition, water depth, seawater temperature, design life, etc
- cable configuration: lazy wave, free hanging, catenary, use of tether
- description of ancillary equipment used to reach the cable configuration
- cable properties, as defined in [3.2.2]
- installation methods
- operation and maintenance activities, e.g. hang off disconnection.

3.2.2 Cable properties

Power cable properties (electrical and mechanical) are to be provided by the cable manufacturer. The following mechanical properties are to be specified:

- power cable and power cores individual components geometry (diameter, thickness, number of wires, lay angles and/or pitch)
- material properties of each layer of the power cores and of the bundle (e.g., young modulus, yield strength)
- power cable unit mass in air and in water
- power cable bending stiffness or moment/curvature relationship, as defined in [3.2.3]
- power cable axial stiffness
- power cable torsional stiffness.

Note 1: If friction effects are non negligible, impact on bending stiffness shall be documented. Parameters that typically influence friction effects are friction factors between components, contact pressure (due to cable tension and external pressure), materials (bitumen), component lay angles.

3.2.3 Bending stiffness

The bending stiffness value is a critical input for global analysis and therefore requires particular attention. It can be affected by at least the following parameters:

- temperature (impact on modulus of polymers, on friction coefficients)
- bitumen (which may be applied for corrosion protection. Viscosity of bitumen varies with temperature, and change of curvature and frequency of bending will affect bending stiffness value)
- tension (contact pressure between layers will be increased with tension applied to the cable).

It is therefore not straight forward to determine the bending stiffness value.

As a minimum, cable bending stiffness is to be specified for full slip conditions, i.e., assuming no friction between cable components, and using nominal geometrical and material parameters. The full slip bending stiffness represents a lower-bound value that is typically applied in dynamic analyses as it normally results in conservative bending radii, e.g., at touchdown and in bend stiffeners.

If the effect of friction is taken into account to obtain a higher and more realistic bending stiffness value, the impact of the different parameters affecting the bending stiffness is to be studied.

3.2.4 Cable structural capacities

The structural capacities of the power cable are to be provided, in particular:

- MBR/ Tension capacity (capacity curve), for storage, installation, and operating condition.
- Compression capacity.
- Crush/squeeze capacity.
- Appropriate materials and friction factors (for external and internal interfaces) data for determination of installation equipment squeezing loads.
- fatigue capacity (for each metallic component) in particular, SN curves for each of the metallic components, and justification regarding their applicability, are to be provided. Impact of temperature on the different properties is to be documented.

Some of these inputs rely on design methodologies. The manufacturer has to justify the robustness and range of applicability of these design methodologies. This is to be supported by test data performed on previous cables cross section that cover the design and loading envelope of purchased cable.

A validation dossier covering these aspects is expected to be provided for review by the Society.

3.3 Q-FMECA

3.3.1 If non-qualified aspects emerge from this review, a Q-FMECA exercise as per App 1 is to be performed with the objectives of determining if a mitigation plan is required or if the proposed design can be accepted as is based on actual utilization within the project conditions. Prototype testing may be requested in case the methodology used to derivate the input value is deemed not sufficiently justified. Q-FMECA shall follow App 1.

3.4 Verification process

3.4.1 General

As part of the design review process, the following documentation is to be issued to the Society for review (if relevant):

- design basis
- cross section datasheet including power cable behavioral properties (lineic weight, stiffnesses, moment curvature relationship)
- global dynamic analysis (extreme, fatigue)
- interference analysis
- installation analysis
- on bottom stability analysis (in line with DNV FP F109)
- local cross section analysis including material selection, components specification, strength capacity, utilization in the different components and fatigue in the different components
- power cable termination (electrical and mechanical) drawings and design reports
- thermal analysis
- electrical analysis including confirmation of the electrical type tests qualification status
- ancillary drawings and design reports.

As part of the verification process, the interventions of the Society normally include:

- Performance of selective independent analyses to verify critical aspects of the design and confirm some calculations results. Typically, independent extreme and fatigue global analysis are carried out on a selection of loadcases.
- Validation of the material selection.
- Regarding the termination design, verification of its mechanical strength and termination of the different power cable component (including tensile armour anchoring). In addition, detailed termination drawings are to be examined.
- Validate ancillary items design specification.

3.4.2 Global analysis

The Client is expected to provide to the Society a global analysis report, detailing all assumptions, inputs, and analysis results.

This global analysis aims at modelling the entire power cable system subject to external loads, in general with hang-off motions imposed.

General recommendations for global analysis of MRE and Offshore units are defined in NI691.

The following aspects are part of the verification activities:

- Correct implementation of power cable mechanical properties.
- Definition of the calculation cases for the different modes of failures, i.e. Design Load Cases. Both extreme (ULS) and fatigue (FLS) conditions are to be covered.
- Modelling of Hang-off motions.

Note 1: MRE units are typically subjected to a combination of wind, wave and current loads. RAO may therefore not be suitable to properly capture MRE unit motions. So-called fully coupled models, i.e. with proper representation of hydrodynamics, moorings, structural dynamics, energy converter loadings and their coupling are typically needed

- Modelling of hydrodynamics loads acting on the power cables and is accessories, with appropriate definition of wave and current induced kinematics on the power cable.

Note 2: Proper phasing between Hang-off motions and wave kinematics should be considered.

Note 3: The sea state and the wave kinematics model as well as the current vertical profile should be defined in accordance with the standard applicable to the MRE and offshore units. Definitions and recommandations may be found in NI691, Sec 2. For hydrodynamic loads, subsea power cables are considered as slender structure (see NI691, Sec 3)

In any case, sensitivity analyses are expected to be performed to demonstrate robustness of results and to cover uncertainties on input data.

3.4.3 Local fatigue analysis

The local fatigue analysis intends to determine the fatigue damage in each metallic component of the power cable cross section. Global loadings (tension and curvature range) are retrieved from fatigue global analysis and local stress are assessed.

The methodology used to determine the transfer function between global loading and stress within the components shall be particularly justified and verified by testings. Testings shall have been performed on similar cross section The calculated fatigue damage, including safety factor for the project shall be inferior to fatigue damage obtained during testing. Impact of temperature on material and fatigue properties shall be assessed, especially at power core level.

Guidance on criteria regarding similarity between cable cross sections are given in CIGRE TB862

3.4.4 Ancillary items

The project certification is to ensure that the whole cable system (including ancillary items) meets the applicable requirements. The design, manufacturing and testing activities related to the ancillary items are part of the review process. In case ancillary items rely on Type-Approved methodologies, the cable Manufacturer has to provide the Type Approval documentation from its supplier for consideration.

If a qualification plan including physical testings is to be performed, Society involvement has to follow guidelines describe in Sec 3, [2].

3.4.5 From a practical point a view, the review work consists both in documentation review (design documentation) as well as, if relevant, in physical attendance during selected qualification testing, dissection, material test or manufacturing trial activities. The communication and resolution of outstanding comments is organized through the issuance of notes of comments and participation to technical meetings between all involved parties.

3.4.6 Deliverable

After satisfactory completion of the verification process, the Society will issue a Design Evaluation Conformity Statement and a technical report describing the review work carried out and establishing that the design, material selection and foreseen manufacturing processes are in accordance with standards requirements and Purchaser specifications

Should an outstanding remark arise from the verification work, it would be highlighted in the Design Evaluation Conformity Statement.

4 Manufacturing Evaluation

4.1 Purpose

4.1.1 The Manufacturing Conformity Statement is the result of the satisfactory conformity assessment of the power cable with regards to the standards requirements as well as the Purchaser's technical specifications.

4.1.2 Inputs

The Manufacturer has to issue a Manufacturing Quality Plan for assessment by the Society.

4.2 Verification process

4.2.1 General

The manufacturing surveillance consists both in physical attendance to the power cores and power cable manufacturing and testing as well as documentation review (e.g. manufacturing record book, justification regarding quality events and non-conformities).

4.2.2 For each project, the Society's scope of interventions typically includes:

- Perform an initial audit at the factory to verify the quality system implemented by the manufacturer and verify the material traceability and the welders' qualification. As a general rule, the quality system of the manufacturers or operators involved are to be certified according to ISO 9001:2015.
- Survey the fabrication of the power cores and power cable as well as its assembly with the termination. The manufacturer has to provide an ITP to this end. Critical manufacturing steps are normally to be witnessed on-site by representatives of the Society.
- Confirm that the power cores and power cable have been manufactured in accordance with the reviewed fabrication procedures, work instructions and control procedures as well as with the specific Purchaser's requirements, if any.
- Review the assessment of potential non-conformities together with the associated corrective actions. To this end, the Manufacturer has to document by dedicated tests and/or calculations that the repairs to the power cable do not compromise the structural or long-term properties of the power cable.
- Review any manufacturing aspect that would be outside a previously validated envelope (e.g. project-specific acceptance criteria for defects or tolerances, new procedure, new machine).
- Witness required production tests.
- Witness the Factory Acceptance Test (FAT) carried out in accordance with standards and purchaser requirements.
- Review the final Manufacturing Record Book (MRB), which contains all relevant information and tests results from the cable manufacturing.
- Verify that the design of the cable has been granted a Design Evaluation Conformity Statement.

- If qualification program and prototype manufacturing and testing has been performed as part of the design phase, the same factory and manufacturing line is to be used for production of commercial cable (including power cores).

Note 1: When power cores are supplied by a manufacturer other than the power cable assembler, the above listed witness and controls are to be performed for both manufacturers and factories.

4.2.3 During this process, the Society will issue inspection reports as well as notes of comments.

4.2.4 The communication and resolution of outstanding comments is organized through the issuance of notes of comments and participation to technical meetings between all involved parties.

4.2.5 Deliverables

After satisfactory completion of the verification process, the Society will issue a Manufacturing Conformity Statement and a technical report describing the review work carried out.

5 Installation Evaluation

5.1 Purpose

5.1.1 The Installation Conformity Statement establishes the conformity between cable capacity versus installation loads as well as purchaser specification.

5.2 Verification process

5.2.1 The following steps are part of the process:

- review of installation steps
- review of installation analysis
- review of installation procedures
- witness of cable installation
- review of final installation documentation.

5.3 Requirements

5.3.1 Installation analyses

Installation analyses are to be performed to determine limiting weather conditions for each step of an operation. These analyses are to demonstrate that cable loads are within allowable limits and establish relevant installation parameters (e.g. minimum allowable lay-back, maximum curvature, cable maximum tension, cable maximum compression, combination of tension-curvatures, maximum allowable stand-by time, fatigue) to ensure that these limits are not exceeded.

5.3.2 Installation procedures

Operational procedures are to be developed based on the results of the installation analyses to ensure that cable acceptance criteria are not exceeded during installation. Limiting weather conditions for each step of the operation are to be clearly stated in the operational procedures, also considering personnel safety and the capacity of installation equipment.

Cable lay parameters such as minimum allowable lay-back, maximum tension allowable and minimum required squeeze are to be specified in the installation procedure to ensure that cable integrity is not jeopardized during laying.

Continuous monitoring of cable touchdown is to be performed to verify that specified lay parameters are maintained during laying

Electrical tests are to be performed, prior to and after installation to ensure that the cable was not damaged during installation.

Evaluations should be made to which electrical tests are required to verify the integrity of the power core insulation system considering for example long lengths, practicalities of test equipment and power demand (ref. CIGRE TB 490). Fibre Optic cable is also to be tested to verify its integrity.

5.3.3 As-laid documentation

Following the completion of cable installation operations, as-laid documentation is to be provided. The data collected during the installation work and related surveys is to be processed and edited for final presentation in the as-built documentation.

5.3.4 Witness of cable installation

Inspection activities are performed to verify integrity of the power cable during installation.

5.3.5 Deliverables

After satisfactory completion of the verification process, the Society will issue an Installation Conformity Statement and a technical report describing the review work carried out.

Section 3 Material and Design Methodology Certification

1 Main principles

1.1 General

1.1.1 The certification of material and design methodology (type approval certification) is an assessment related to the subsea power cable technology of a Manufacturer. It is therefore generic and not meant to be specific to a project or a power cable design.

1.1.2 The Design methodology Verification Activities (also called Type Approval certification) is structured around the review of the following blocks:

- design methodologies (mechanical behavioral properties, mechanical limit states, temperature distribution), associated tools and design rule
- material qualification dossiers
- manufacturing process.

Some elements put forward by the Manufacturer for integration into the Type Approval may be part of completed or on-going new technology qualification programs. The specific verification process for new technologies as well as their integration within the Type Approval work is described in App 1.

1.1.3 Terminology

The terminology Type Approval certification is consistent with the API 17J definition given to the IVA and its role: "Independent party or group, selected by the Manufacturer, who is responsible for the review and certification of the indicated product concept (e.g. pipe and end fitting concept) and flexible pipe, associated design, manufacturing methodologies and criteria, material qualification and prototype performance based on the technical literature, analyses, results and other information provided by the Manufacturer to establish the range of applicability".

2 Component and prototype testing

2.1 General

2.1.1 Due to their complex nature, the various number of failure modes involved as well as the use of tailor-made designs, subsea power cable are prone to extensive qualification testing campaigns. These tests can be performed at various scales (Small-scale, mid-scale or full-scale) and used either during Manufacturer's internal development campaigns or in a project phase in order to demonstrate the performances of the product to the End-user.

Prototype and material testing can be carried out for multiple purposes and it is common that a single test meets simultaneous objectives. Example of testing purpose include:

- the evaluation of the power cable performance against a targeted failure mode
- the evaluation of the power cable global characteristics (e.g. stiffnesses)
- the measurement of power cable in-situ local quantities (e.g. wire strain, local temperature profile across power cable section)
- the validation of a design methodology
- the qualification of a material in in-situ conditions
- the qualification of a manufacturing process
- the extension of the qualification range of a design methodology or power cable component / material
- the determination of a component property (e.g. wire S-N curve, polymer stress strain curve).

2.2 Society's involvement

2.2.1 Experimental evidence from testing is a key aspect of the Type Approval process whether it is prediction methodology validation or material qualification.

The Society is to be involved in the production of any experimental data meant to be considered for consolidation within the Type Approval, from sample manufacturing until test execution and prototype dissection, whenever relevant.

Exceptionally, if no IVA involvement was made possible (e.g. for experimental data collected before the initiation of the Type Approval process), a comprehensive testing documentation is to be produced, including as a minimum the sample manufacturing report, the test execution report and the prototype dissection report, whenever relevant.

2.3 Requirements

2.3.1 Test specimens

The test specimens are to be demonstrated to be designed and manufactured in accordance with the methods in force. Exception is made for early qualification phases of new products for which preproduction samples can be accepted, provided that their representativity towards actual commercial products can be documented.

2.3.2 Quality plan

An Inspection and Testing Plan (ITP) is to be established for prototype samples manufacturing, testing and dissection and is to be submitted to the Society. This will identify the relevant fabrication and control procedures, the intended attendance / witnessing by the manufacturing, control and development project team personnel, and include the intended Society's involvement.

2.3.3 Sample manufacturing

The involvement of the Society through inspection / auditing will be determined through quality plan (or equivalent) mark-up prior to the start of the manufacturing process of samples fabrication and preparation for testing. This involvement will aim at concluding that the test samples may be considered sufficiently representative of the envisaged project production.

Manufacturing techniques are to ensure that no significant variation of properties would occur throughout the manufacturing process.

Whenever relevant, the test procedure has to include objective acceptance criteria.

2.3.4 Test execution

The test procedures and calibration certificates of the test equipment are to be presented to the Surveyor who will attend to the test as per the agreed involvement in Quality Plan / Inspection and Test Plan (ITP) (or equivalent).

2.3.5 Documentation to be produced

For Mid-scale and Full-scale tests, the test documentation to be produced by the Manufacturer has to include:

- the tested product datasheet
- the test sample manufacturing data book
- the test procedure
- the test report
- the analysis report, if relevant
- the dissection report
- any complementary investigation report (laboratory investigations, finite elements analyses).

For Small-scale tests, the documentation to be established has to include:

- the raw material specification and raw material supplier(s) used for the test samples
- test specimen(s) material certificates
- the test procedure
- the test reports
- the evidence of attendance of an IVA inspector during the tests
- any complementary expertise of the specimens (e.g. Ultrasonic Testing, Magnetic Particle Inspection, corrosion scale analysis, micrographis).

After inspection / witnessing activities, an inspection report will be issued by the Society, detailing the scope of the inspection as well as the objective conclusions.

2.3.6 Treatment of non-Conformity

In case a test acceptance criterion would fail to be met, the Manufacturer has to perform a root cause analysis in order to identify the causes of the non-conformity and define corrective and preventive actions. The analysis report of this non-conformity is to be presented to the Society for review.

3 Design methodologies

3.1 General

3.1.1 Purpose

In order to optimize the subsea power cable qualification campaigns based on full-scale testing, the validation of a design methodology allows to consolidate historical qualification campaigns into a range of products for which a predictive methodology can be safely applied without requiring additional testing.

This work generally initiates on a theoretical basis compared with prototype testing.

3.1.2 Minimum aspects of a design methodology

A design methodology has to encompass the following:

- a theoretical model, as defined in [3.4]
- an experimental verification of the theoretical model, as defined in [3.5]
- a calculation procedure for subsea power cable design [3.6].

3.1.3 Verification process

In order to assess a given design methodology, a systematic approach is followed:

- as a first step of the review, the theoretical model is assessed.
- in a second step of the review, the experimental validation of the theoretical model is scrutinized
- in a third step of the review, the calculation procedure to be used for power cable design (i.e. the design methodology) is assessed
- in a fourth and final step of the review, the conclusions of the assessment of the design methodology including its range of use are issued through a technical report, supplemented by a Certificate.

3.1.4 Design methodologies to be considered

The following non-exhaustive list presents some examples of design methodologies that are considered important to be covered by IVA certification. The difference is made between failure models whose objective is to predict a limit state of the subsea power cable and the behavioral models whose objective is to provide an intermediate design quantity.

a) Failure models:
   - overbending
   - damaging pull
   - crushing
   - tension curvature capacity domain
   - termination anchoring capacity
   - bird caging or lateral buckling of tensile armours
   - fatigue of tensile armours
   - fatigue of conductor and screen wires
   - fatigue of polymer
   - corrosion of metallic components
   - abrasion/wear of external sheath
   - power cable slippage during installation.

b) Behavioral models
   - determination of power cable stiffness properties, including non-linear moment-curvature relationship
   - determination of stress and strains in power cable layers under axis-symmetric loadings
   - determination of stress and strains in power cable layers under axis-symmetric and bending loadings
   - determination of the temperature field in the power cable
   - determination of power cable curvature inside bend stiffener.

3.1.5 Documentation to be submitted

A validation dossier, as defined in [3.2], is to be submitted for review.

3.2 Validation dossier

3.2.1 Documentation

The minimal documentation to be provided by the Manufacturer for the assessment of a design methodology includes:

- a theoretical report, describing the phenomenon assessed as well as the theoretical model considered to predict the limit state or the quantity scrutinized
- an experimental report (or set of reports) collecting all the experimental evidence put forward by the Manufacturer regarding the assessed phenomenon
- a correlation report showing the comparison between the experimental results and the theoretical model predictions

3.2.2 A design instructions report describing how the developed model is to be used during engineering studies

3.2.3 Whenever relevant, additional documentation such as technical literature or Manufacturer's track record can be added to the validation dossier

3.2.4 The range of applicability pertaining to the scrutinized methodology, as targeted by the Manufacturer.

3.3 Theoretical model

3.3.1 As part of the review of the theoretical model, the following aspects are taken into consideration:

- The nature of the theoretical model:

  Depending on the complexity of the problem to be addressed and the level of optimization to be reached, the theoretical model can be of various natures from simple closed-form expressions to a multi-physic numeric calculation.
- The physical description of the phenomena involved and the relevancy of these phenomena with respect to the failure mode or physical quantity to be estimated.
- The simplifications and assumptions of the model as well as their impact on the model predictions.
- The limitations of the model due for instance to lack of experimental validation, over-simplifications or non-inclusion of some phenomena.
- The number of model input parameters:

  The total number of input parameters of the model is to be identified. At the stage of the definition of the design calculation procedure, the design values to be assigned to these parameters are to be clearly established.
- The classification of model input parameters:

  The nature of the input parameters is to be identified. In particular, the distinction between varying parameters (e.g. geometrical or material data) and frozen model parameters (e.g. calibration data) is to be made.
- The calculation of intermediary variables:

  The study of such variables can be useful to better understand the model and/or provide intermediate validation elements.
- The model sensitivity to the input parameters:

  Parametric model runs should be studied (if relevant) to demonstrate the suitability of the model in a given range of use.
- The behavior of the model:

  As much as possible, the physics of the model should remain understandable. In particular, the trends observed by the parametric runs should be explainable and/or experimentally observed.
- The stability of the model:

  Together with the need for optimized methodologies, the design models tend to be more complicated by integrating non-linearities (e.g. material laws, large displacements, contacts, friction) and using numerical solving methods. In this context, the stability of the theoretical models in their whole range of use should be studied in order to identify potential risks of non-convergence or unexpected results.
- The need for calibration of the model:

  Depending on the degree of simplification of the model, the values of some parameters may need to be calibrated based on empirical data.

3.4 Experimental validation

3.4.1 As part of the review of the experimental validation of the theoretical model, the aspects mentioned from [3.4.2] to [3.4.12] are taken into consideration.

3.4.2 The scale of the experimental validation

The experimental validation material can be based on small-scale testing, mid-scale testing, full-scale testing or combinations of all of these. As a general rule, for the failure and behavioral models under consideration, there are very few cases where a full-scale campaign test can be avoided in order to certify a design methodology.

3.4.3 Test specimens

As a rule, the tests specimens are to comply with the manufacturing method.

If for some reasons the design or manufacture of the test specimen does not comply with the methods in place (e.g. use of a leftover sample, simplified cross-section, non-conformity during manufacturing), it is to be demonstrated that the limit state / behavior scrutinized is unaffected by this.

3.4.4 The representativeness of the experimental set-up

A special attention is paid to the loads and boundary conditions of the experimental set-up with respect to actual offshore conditions.

The specific case of full-scale fatigue testing is scrutinized with care since contrary to most other full-scale tests, the test loads do not coincide with offshore loads due to the need for test acceleration. Under these accelerated test conditions, the risk of modifying the real failure modes should be estimated (e.g. creation or suppression of failure modes).

3.4.5 The full-scale testing artefacts

Even if the full-scale testing is the most representative experimental validation, the test rig can still suffer from testing artefacts such as short length effects or unrealistic boundary conditions. Such effects need to be identified and considered by the Manufacturer in the model validation as much as possible.

3.4.6 The validating tests stopping criterion

When the objective of a test is the validation of a theoretical model, two categories of tests can be foreseen: destructive tests and non-destructive tests.

For validation of design methodologies predicting failure modes, destructive tests are deemed to be strongly preferable as they demonstrate that the actual observed failure mode is the one predicted and allows establishing the safety margins embodied by the model.

For validation of design methodologies predicting behavioral models or in complement of the aforementioned destructive tests, non-destructive tests are valuable provided that a large representative range of loading conditions is investigated and that the test samples are properly instrumented.

3.4.7 The intermediate validation

The validation of a failure model based on destructive testing is carried out through the comparison of an ultimate experimental value (e.g. number of cycles to failure) with the value predicted by the model.

In parallel, in many instances, some elements of validation of the model can be provided through intermediate physical variables which experimental values can be obtained by a specific instrumentation of the sample. Even if these intermediate variables do not demonstrate the final failure mode, they allow gaining confidence in the model predictions. Such validation is particularly important when the scrutinized failure mode cannot be reached experimentally (rig limitations, precedence of another failure mode in the conditions of the test) or when the model relies on a high number of parameters.

Some examples of intermediate variables include ovality measurements (crushing models), curvature measurements (tension-bending tests) or strain measurements (axis-symmetric behavior and fatigue models).

3.4.8 The number and extent of experimental data

The range of loading conditions (loads, boundary conditions, environment), geometries and materials investigated should be duly taken into consideration for design methodology validation.

3.4.9 Selection of data for model validation

Any experimental data discarded for model validation are to be duly justified by the Manufacturer.

3.4.10 Outliers

An explanation related to the outliers, for which a significant deviation between the test results and the model prediction are observed, should be provided by the Manufacturer.

3.4.11 Modelling of the validation test

The first step of comparing experimental values with predicted values is to run the model for the specific test sample and conditions assessed.

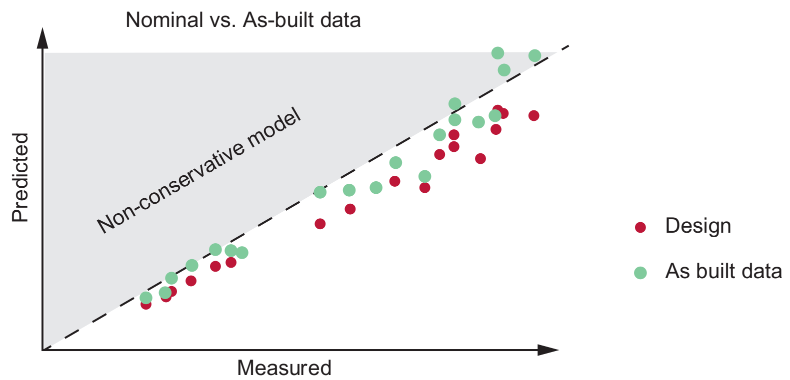
Regarding the choice of the value of the input parameters defined for the model, the use of the test actual values (e.g. geometrical as built values, real material characteristics, loadings or annulus composition actually measured …) is to be used whenever possible. If impossible, most probable values should be used instead. The non-respect of this clause can lead to the establishment of non-conservative design models (see Fig 1).

All the input data considered in the modelling of the validation test are to be made available to the Society.

The Society may conduct independent analyses (analytical, Finite Elements) in order to confirm:

- the correct implementation of the model
- input data
- assessment of parameter sensitivity.

Figure 1 : Use of as built data

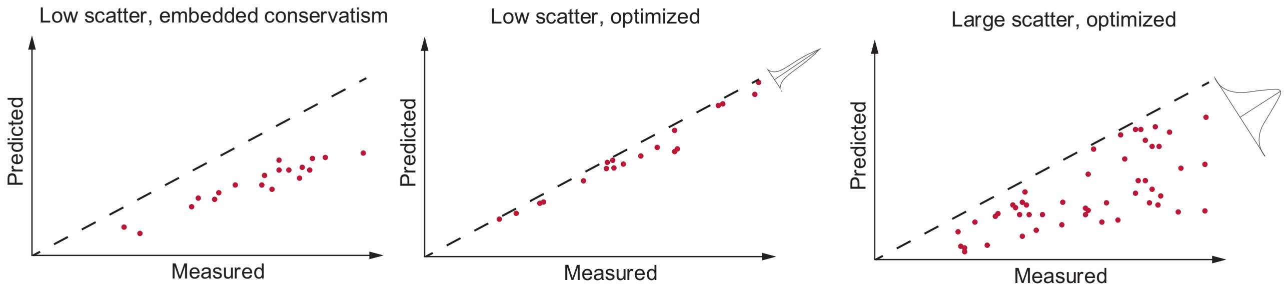


3.4.12 Correlation between model predictions and tests results

For each relevant experimental data (e.g. test failure point, intermediate measurements, …), a comparison is to be carried out between the predicted value, calculated as indicated in the previous point, and the measured value, taking into account any relevant measurement uncertainties. If the raw model predictions have been a posteriori corrected by a calibration factor to better match the experimental data, the calibration process is to be duly explained.

The scatter of the model predictions compared to experimental data, as an indication of the model accuracy, are to be provided. Some examples of correlation plots are shown in Fig 2.

Figure 2 : Correlation plots



3.5 Calculation procedure

3.5.1 During the review phase of the calculation procedure, the following aspects are taken into consideration:

- The user's interface:
  - in order to be useable by the engineering departments and allow having a frozen approach for certification, the design methodologies, typically developed by R&D departments, are to be integrated in spreadsheets or computer programs, identified by the version number that the design methodology certificate covers
  - it is to be ensured that the nature of the input and output data are well documented to avoid user's inputting errors
  - any parameter frozen in the model and identified as such during the validation procedure are not to be modifiable by the user
  - all the input data of the methodology are to be explicitly stated in the output report
  - a particular attention is paid to the design methodologies based on finite elements calculations as this method can be difficult to standardize and certify due to the high number of parameters involved.
- The determination of the design data: the design methodology has to clearly indicate the design data to be considered by the user. For example, the consideration of the manufacturing tolerances combination, the design conditions or load cases to be studied should be identified.
- The safety margins: the way the safety margins are applied on top of a failure point predicted by a methodology (e.g. on loads, resistances) are to be defined by the Manufacturer, with a particular focus on highly non-linear models. Several ways of considering safety margins may be envisaged: Choice of conservative design values, choice of conservative design scenarios, application of global safety factors or application of partial safety factors.

3.6 Assessment report

3.6.1 In conclusion of the verification work, a detailed assessment report is issued by the Society. This report includes:

a) the description of the theoretical model

b) the description of the experimental validation material

c) the description of the correlation between test results and model predictions

d) the description of the design procedure, including the choice of design data and application of safety margins

e) the society position regarding the assumptions, uncertainties and limits of applicability of the methodology

f) the Society position regarding the range of applicability of the design methodology, also called qualified range or certified range. The definition of this envelope is the logical outcome of all the aforementioned assessment work. As each case is different, the establishment of such ranges necessarily involves sound engineering judgment.

3.6.2 Range of applicability

The following basic principles are to be followed:

- The parameters that characterize the range are defined based on the physical model assessed. The total number of parameters is chosen to be sufficiently high to safely establish the limits of the design methodology but remaining intelligible.

- The range is structured around the experimental material used for the validation of the model. The extrapolation of this testing range towards a qualified range largely depends on a lot of aspects that are taken into account such as:
  - the confidence in the theoretical model
  - the robustness of the test database
  - the need for calibration of the methodology
  - the levels of safety margin considered for design.
- The qualified range aims at a reasonable trade-off between a too restrictive domain of use of the methodology (e.g. limiting the use of the methodology to tested power cables only would disregard that a prediction model exists and may involve unnecessary testing costs) and a too wide domain of use of the methodology (e.g. by allowing power cable designs or loadings clearly different from the ones actually tested).

  Parameters to be considered for the definition of the validated range may include:
  - nominal voltage,
  - cable overall diameter
  - power core type
  - conductor material and cross section geometry
  - insulation material and thickness
  - type of metallic screen
  - armour wire diameter or other strength element size
  - components lay angles
  - loadings on the different components (i.e. maximum allowable mean stress/stress range on copper conductor).

4 Material qualification

4.1 General

4.1.1 Due to project conditions (increased voltage and mechanical loadings), manufacturers regularly undertake qualification of new materials or carry out development aiming at extending the domain of use of an existing material.

Note 1: As an example, the electrical insulation layer of the power cable is subjected to continuous development.

4.1.2 Verification process

The assessment of a given material results in the assessment of:

- procurement and raw material specification
- manufacturing process at plant, e.g. polymer extrusion, or armour wires laying
- material dossier documenting material properties and chemical compatibility
- allowable envelope of utilization of the material defined in design rules.

The requirements and verification procedure for material qualification are described from [4.2] to [4.4].

4.1.3 Deliverable

The Type Approval certificate and report include a list of materials covered, as assessed, together with the range of applicability, validated in terms of e.g. electrical voltage, internal and external temperatures, external pressures and relevant limitations. An associated assessment report is also issued [4.6].

4.2 Procurement

4.2.1 The following points are to be documented:

- intended range of use (electrical voltage, static and/or dynamic application)
- raw material identification and specification, justification of control and tests required from Manufacturer.
- supplier's QA system Certificate
- dispersions in procured material characteristics are to be assessed in order to confirm that product expected performance are achieved
- fiber optic specification
- in case of a power cable manufacturer purchasing the power cores from external suppliers, the power core specification should be provided for review.

4.3 Manufacturing process

4.3.1 With respect to the material transformation carried out in the plant, the main manufacturing process are to be documented and validated including:

- conductor manufacturing process
- extrusion of insulation layer, conductor and insulation screens, external sheath. Regarding the insulation layer (followed sometimes by a cross-linking process, and by degassing stage) at the plant of power core Manufacturer, the manufacturing process concerns the overall steps of extrusion process including the control methods on raw (at receipt, during storage in the Manufacturer's warehouse and just prior to use deemed necessary) and extruded products, including the repair process
- metallic screen fabrication (wires, braiding, corrugated)
- extrusion of fillers
- armour wire laying
- terminations/ end-fitting mounting
- factory acceptance testing.

Transformability of the procured materials in the various manufacturing process machines, to reach the desired results and satisfy the desired function, and stability of the process within identified tolerances, selection of tools etc., to have reproductible and reliable results, is to be secured through adequate procedures, work instructions. The Manufacturer has to establish that no significant variation of properties can occur throughout the manufacturing process, hence that any section cut out may be acceptable as representative for testing.

Important quality parameters have to be recorded as necessary. Required controls to ensure all fabrication (and repair) parameters and end-results within qualified tolerances are also to be well defined in procedures, recording formats available.

4.4 Material testing

4.4.1 The list of tests to be performed on a given material shall be based on a Q-FMECA. This shall include small scale, middle scale and full-scale testing.

The tests are to be performed with samples representative of materials in layers produced by the Manufacturer to the extent required to cover the intended range of use.

4.4.2 Wet ageing testing

For wet design subsea power cable, wet ageing testing of insulation layers are to be performed following Cigre TB 722:2020 to verify resistance versus water treeing phenomenon.

4.4.3 Qualification of water barrier

For dry design cable, water barrier has to be properly qualified. Watertightness of the barrier has to be demonstrated according to Cigre TB 446 and Cigre TB 490.

4.4.4 Fatigue testing

The fatigue performances of steel wires (conductors, metallic screen, tensile armours or other strength members) represent a crucial aspect of the Type Approval of dynamic subsea power cable. Significant fatigue testing campaigns are to be launched aiming at covering the different combinations of wire grades and environment that may be encountered.

Small scale fatigue testing and impact of temperature (at conductor level and on creep) is to be documented.

The Society assessment normally consists in a combination of documentary review, including test procedures as well as third party inspection / witnessing.

4.4.5 Selection of the scale

In addition to small scale laboratory tests, it is important to document the correct behavior of the material being qualified in its actual environment, taking into account in particular the different interactions with other layers seen by the material.

Examples of interactions difficult to be captured in small scale testing, hence the need of mid-scale / full-scale tests, are given hereafter:

- high contact pressures combined with relative displacements between layers
- multiaxial loadings
- combined pressure loadings, temperature loadings (constant or transient), and mechanical loadings / restraint (leading to creep or relaxation effects)
- friction characteristics and sliding resistance of the subsea power cable interface layers during installation or service life.

The list of required full scale tests is to be established as required by aspects mentioned above, other design change situations when relevant, and based on a Q-FMECA findings (see App 1) and relevant considerations to manage risks as low as reasonably practicable.

4.5 Range of applicability

4.5.1 The range of applicability is to be proposed by the Manufacturer for review by the Society, as a result of the qualification activities carried out and in relation with the intended market needs as well as the limitations found.

4.6 Assessment report

4.6.1 In conclusion of the verification work, a detailed report is issued to reflect the assessment activities, mentioning the evidence gathered, and allowing to establish the certificate for incorporation of the material into the Type Approval Certificate with a validity period of normally 5 years.

Section 4 Operational Management

1 General

1.1 Scope

1.1.1 Operational management relates to the way the subsea power cable system is operated throughout its lifetime, including data collection, monitoring, inspections, as well as potential damage assessment.

The Owner of the power cable system may request a Third-Party review to the Society in order to state that its power cable system meets expected performance and safety requirements, defined by the Owner or by National Authorities. Examples of Third-Party work carried out during the operation of power cable system include the validation of the implementation of an integrity management system and the evaluation of the fitness for service of the system following an operational incident.

For any operational-related assessment work, the Society will issue a technical report describing the verification activities carried out as well as the conclusions and recommendations, if any.

2 Integrity management system

2.1 General

2.1.1 The integrity management system is a quality process set up by the Owner in order to establish the historicity of the operated power cable system, covering the data collection and storage of various aspects such as: Original design and manufacturing documentation, installation data, operational data, voltage / power data, thermal data, environmental data, inspection results, monitoring, incidents, damage assessments, repairs, retrieval and dissection of other cables in the field, mitigation actions.

While the set-up of an integrity management system is not sufficient to establish the power cable system fitness for service or lifetime extension, it is considered to be a strong prerequisite to be submitted to the Society for any assessment work, in order to confirm that the operational data is robust and comprehensive.

2.2 Documentation

2.2.1 The End-user is responsible for safe operation of the submarine power cable system. With this objective, an integrity management system is to be devised and followed by the End-user.

As part of the integrity management system, execution of the monitoring and inspection plan is to be documented including:

- recording of incidents
- history of current voltage, intensity, power operating records, including analysis of conditions out of specification (e.g. above maximum allowable power)
- regular subsea inspection surveys videos and reports of power cable system aiming at detecting situations potentially impacting the power cable pipe system integrity (e.g. outer sheath damage, marine growth above design premise assumptions, condition of ancillary items, cable global configuration geometry, on-bottom stability issues, indications of impact between cable and fishing gear)
- monitoring of the insulation material condition using e.g. partial discharge measurements
- evidence of maintenance of the cathodic protection system
- actual metocean conditions experienced during operation and actual floating platform motions, allowing to document a possible margin (or gap) versus the assumptions of the extreme and fatigue global dynamic analyses
- use of validated monitoring solutions implemented in the power cable system (typically FO cable for temperature and strain distribution).

Above information are key essential data for subsequent condition assessment and studies.

Appendix 1 Qualification of New Technology

1 Failure mode effects and criticality analysis (Q-FMECA)

1.1 General

1.1.1 When new technologies are developed, a common exercise to define the qualification program aimed at demonstrating the suitability of the new technology is to carry out a Q-FMECA (Qualification Failure Mode Effects and Criticality Analysis (Q-FMECA)).

1.1.2 Failure modes and functional analysis

The Q-FMECA exercise is to be exhaustive, scrutinizing all possible failure modes versus all functions the new technology is expected to fulfil during all phases of its life related to the dynamic power cable. It is therefore a prerequisite to carry out a detailed functional analysis, identifying all expected functions throughout procurement, fabrication of the cable structure and mounting of the termination at the power cable manufacturing plant, offshore site installation (and recovery in service, similar to installation situation), and final use by Client.

As part of the Q-FMECA process, it is essential to ensure that failure modes susceptible to be triggered by the introduction of the new technology have been ascertained.

1.1.3 Process

The proposed format of the Q-FMECA is based upon existing FMECA types (API 17N, NI525, App 1.) with a focus on identifying required qualification activities for each identified failure mechanism. The Q-FMECA process investigates in a systematic way all functions fulfilled by the considered new technology in the dynamic power cable, throughout all phases of its life, from procurement to end of life, to identify all corresponding failures, their modes, causes and consequences. The purpose shall be to identify qualifications required to prevent or mitigate all these possible failures, as much as reasonably practicable.

1.1.4 Tests

The list of full-scale tests required to achieve qualification of the new technology are to be established, based on Q-FMECA findings and relevant considerations to manage risks as low as reasonably practicable.

Examples of full-scale test can include:

- full scale test to verify the bending stiffness of the dynamic power cable, as this property is a very basic information with significant impact on the global dynamic behavior / curvature predictions
- full scale fatigue test to verify the safety margin in fatigue and the critical components under fatigue loading. It is to be noted that the fatigue test program should represent the project fatigue loads with an appropriate safety factor.

1.1.5 In absence of Manufacturer's own risk notation system, the notation system given in Tab 1 may be applied.

1.1.6 Criticality

When all concerned parties agree to decide on required qualification based on consensus, the criticality quantification (Sx F) or (S x F x D) may be omitted, the exercise is then named FMEA.

2 Qualification program documentation

2.1 General

2.1.1 Based on the outcome of the Q-FME(C)A carried out, the Manufacturer has to work out the required program of qualification and prepare the corresponding documentation to organize the actions. The documentation to be established includes:

- the identification of the goals and nature of the solution
- the targeted range of use (e.g. envelope of conditions)
- the Q-FME(C)A table (see Tab 2) establishing the risks and uncertainties that need to be addressed, supporting the Qualification Program
- the qualification envelope, schedule of fabrication of test samples, with associated procedures (fabrication and control),
- Inspection and Test Plan ITP (or equivalent) showing the intended IVA involvement
- the list of qualification tests and associated procedures
- the list of engineering work / analyses to complement or justify the testing
- the qualification planning.

Table 1 : Generic Q-FMECA notation system

S. Severity of failure		F. Frequency of occurrence		D. Probability of detection	
1	Hardly Noticeable	1	Unlikely probability	1	Very high probability
2	Very small effects	2	Very small	2	High
3	Small effects	3	Small	3	Moderate
4	Moderate effects	4	Moderate	4	Small
5	High effects	5	High	5	Very small
6	Very high effects	6	Very high	6	Unlikely

Table 2 : Generic Q-FMECA table

No.	Step **(1)**	Pipe art **(2)**	Possible failure mode **(3)**	Causes of failure **(4)**	Effects of the failure **(5)**	S. Severity ranking **(6)**	F. Frequency ranking **(6)**	D. Detection ranking **(6)**	S.F Risk category **(6)**	Risk criticality **(7)**	Mitigation through Qualification activity **(8)**

(1) Procurement, Design, Manufacturing, Installation, Production.
(2) Material, pipe structure, end-fitting.
(3) Manner in which an item fails. Example: break of pressure vault.
(4) Cause the leads to the failure of an item. Example: material defect leading to breakage.
(5) Consequence of failure mode in items of the operation, function or status of the item. Consequences of failure shall not be limited to the item but also to surrounding and interfacing systems, and HSE. Example: burst of pipe.
(6) See Tab 1 for notation system.
(7) S x F x D.
(8) Mitigation required when: S x F x D is equal or greater than 20, or S x F equal to greater than 6.

3 Society involvement

3.1 Time schedule

3.1.1 While the Technology Qualification phase can be carried out in a first stage before the outcome of the qualification campaign is submitted for Type Approval integration, it is recommended that the Society is involved in the Q-FMECA process in order to review the qualification strategy during the early phase of development of the new technology and avoid the raising of outstanding issues after the finalization of the qualification campaign during the Type-Approval work.

3.2 Principles

3.2.1 As a general rule, the Q-FMECA session is a joint exercise during which both Manufacturer's and the Society experts are gathered with the objective of establishing the Q-FMECA table. Manufacturer and FMECA can be prepared in advance before being merged as part as the Q-FMECA session during which the final Q-FMECA is validated.

In case of involvement after the definition of the qualification plan, the Society will perform an internal Q-FMECA in order to assess the Manufacturer's Q-FMECA. In case a gap is identified, mitigation actions are to be discussed between the Society and Manufacturer (e.g. supplementary qualification activities, reduced range of use compared to initially targeted).

3.3 Assessment process

3.3.1 Assessment work consist in the following activities:

- The review of the qualification program, considering the Q-FMECA as well as the agreement on the Society's involvement during the qualification activities.
- The follow-up of the qualification activities, as defined by the qualification plan. For the review of the qualification activities, all the requirements established in Sec 2 are applicable, whenever relevant.

4 Deliverables

4.1 General

4.1.1 Various deliverables may be issued from the definition of the Q-FMECA until the execution of the qualification plan.

Basic deliverables for the qualification of new technologies include:

- a statement of endorsement of the qualification program
- a certificate and technical report summarizing the outcome of the qualification activities, establishing the conformity of the new technology to relevant standards as well as to potential additional requirements and presenting the range of use / application of the new technology.

4.2 Relation with Type Approval Certification

4.2.1 As a general rule, the final certificate and technical report associated to the qualification of a new technology can be consolidated through the Type Approval documentation. It is common that the qualification activities related to a new technology impact various items covered in the Type Approval. For instance, the development of a new insulation layer will potentially expand the design methodologies, the qualified materials or the manufacturing methods. In such cases, modification of the existing Type Approval certificates are to be requested to the Society in order to reflect the outcome of the qualification activities.

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