ACP OCRP 5 2022

Recommended Practice for Design, Deployment, and Operation of Submarine Cable in the United States (OCRP5)

AMERICAN CLEAN POWER ASSOCIATION
Standards Committee

202.383.2500 | 1501 M St. NW, Suite 900, Washington DC 20005 | cleanpower.org

AMERICAN NATIONAL STANDARD

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria for approval have been met by the standards developer. Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity.

Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation of any American National Standard. Moreover, no person should have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretations should be addressed to the secretariat or sponsor whose name appears on the title page of this standard.

Caution Notice: This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken periodically to reaffirm, revise, or withdraw this standard. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute, 11 West 42nd Street, New York, NY, 10036, phone (212) 642-4900.

AMERICAN CLEAN POWER ASSOCIATION STANDARDS

Standards promulgated by the American Clean Power Association (ACP) conform to the ACP Standards Development Procedures adopted by the ACP Board of Directors. The procedures are intended to ensure that ACP standards reflect a consensus to persons substantially affected by the standard. The ACP Standards Development Procedures are intended to be in compliance with the American National Standards Institute (ANSI) Essential Requirements. Standards developed under the ACP Standards Development Procedures are intended to be eligible for adoption as American National Standards.

Published by:
American Clean Power Association
1501 M Street, N.W.,
Suite 900
Washington D.C. 20005
www.cleanpower.org

NOTICE AND DISCLAIMER

The American Clean Power Association ("ACP") has provided this Document for the use subject to important notices and legal disclaimers. This Document is proprietary, and its use is subject to a legally binding license agreement and disclaimer ("Agreement") described herein and available on ACP's website at https://cleanpower.org/standards-development/, which may be updated from time to time. Do not use this Document for any purpose unless and until you read the agreement. By viewing or otherwise using this Document, you hereby warrant and represent that you have read and agree to be legally bound by the agreement and are authorized to bind not only yourself to the agreement, but the organization for which you are accessing this Document.

Notice and Disclaimer Concerning ANSI Process

Certain ACP standards and best practice publications, of which the Document contained herein is one, are developed through a voluntary consensus standards development process. ACP administered the process in accordance with the procedures of the American National Standards Institute (ANSI) to promote fairness in the development of consensus. This process brings together volunteers and/or seeks out the views of persons who have an interest in the topic covered by this Document. The information in this Document was considered technically sound by the consensus of persons engaged in the development and approval of the Document at the time it was developed. Consensus does not necessarily mean that there is unanimous agreement among every person participating in the development of this Document.

Notice and Disclaimer Concerning Accuracy of Information and Liability Concerning the Use of ACP Publications

Every effort has been made to assure the accuracy and reliability of the data and information contained in this Document; however, ACP does not write this Document and it does not independently test, evaluate or verify the accuracy or completeness of any information or the soundness of any judgments contained in its publications. ACP disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein.

In publishing and making this Document available, ACP is not undertaking to render professional or other services for or on behalf of any person or entity. This Document, and ACP publications in general, necessarily address problems of a general nature. ACP disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein and disclaims and makes no warranty that the information in this Document or its other publications will fulfilll any of your particular purposes or needs. ACP does not undertake to guarantee the performance of any individual manufacturer or seller's products or services by virtue of this Document.

Users of this Document should not rely exclusively on the information contained in this Document and should apply sound business, scientific, engineering, and safety judgment in employing the information contained herein or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. Information and other standards on the topic covered by this Document may be available from other sources, which the user may wish to consult for additional views or information not covered by this Document.

Use of this Document is strictly voluntary. ACP has no power, nor does it undertake to police or enforce compliance with the contents of this Document. ACP does not certify, test or inspect products, designs or installations for safety or health purposes. Any certification or other statement of compliance with any health or safety–related information in this Document should not be attributable to ACP and is solely the responsibility of the certifier or maker of the statement.

ACP disclaims liability for any personal injury, property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this Document or on any of its other publications, even if advised of the possibility of such damage and regardless of whether such damage was foreseeable. In addition, ACP does not warrant or represent that the use of the material contained in this Document is free from patent infringement. ACP publications are supplied “AS IS” and “WITH ALL FAULTS.”

Laws & Regulations

When using this Document, local, state and federal laws and regulations should be reviewed. Compliance with the provisions this Document does not constitute compliance to any applicable legal requirements. In making its publications and this Document available, ACP does not intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so. Users of this Document and other ACP publications should take into account state, local, Federal, or international data privacy and data ownership requirements in the context of assessing and using the publications in compliance with applicable legal requirements.

ACP Wind Technical Standards Committee members, at the time the standard was approved:

Company Name	Primary	Alternate
Acciona Energy USA Global LLC	Brian Mathis	Richard Heier
Advanced Insulation Systems LLC	Mike Sherman	
Alimak Group USA Inc.	Luke Metzinger	
American Renewable Energy Standards and Certification Association (ARESCA)	Brian McNiff	Robert Sherwin
ArcVera Renewables	John Bosche	Gregory Poulos
Avangrid Renewables	Christopher Morris	Agustin Melero
Barr Engineering Company	Kirk Morgan	Cordelle Thomasma
Bergey Windpower Co. Inc.	Mike Bergey	
Boulder Wind Consulting	Sandy Butterfield	
Clear Wind	Matt McCabe	
Clobotics Corporation	Nicholas Acorn	Rogers Weed
CTE WIND USA, Inc. - CIVIL ENGINEERING	Jomaa Ben Hassine	Alexander Martin
DNV	Brian Kramak	Dayton Griffin
Elevator Industry Work Preservation Fund	Carisa Barrett	Eric Rogers
ENERCON Canada Inc.	Tarik Daqoune	
Energy Systems Integration Group (ESIG)	Cody Craig	Stanton Peterson
Exponent	Timothy Morse	Bernard Roesler
GE Renewable Energy	Mark Helton	Toby Gillespie
HSB - Hartford Steam Boiler	Linkesh Diwan	Simon Krebs
Leeward Renewable Energy	Ronald Grife	
Marmon Electrical - RSCC Wire & Cable	Damian Billeaudeau	Phil Laudiciana
MotorDoc LLC	Howard W. Penrose	Branka Stemack
National Renewable Energy Laboratory	Jeroen van Dam	Paul Veers
NRG Systems	Rob Cole	Steven Clark
nVent ERICO	Tom Bendlak	Dan Holm
Pattern Energy Group Services, LP	Michael Edds	
Penn State University	Susan W. Stewart	
RE Innovations LLC	Joseph Spossey	
Sargent & Lundy L.L.C.	David Jolivet	
Siemens Gamesa Renewable Energy	Masoud Sharifi	
Small Wind Certification Council	Shawn Martin	
Spire Engineering Services LLC	Robert Sheppard	
Terra-Gen LLC	Yuanlong Hu	

U.S. Department of Energy	Jim Ahlgrimm	Michael Derby
UL LLC	Tim Zgonena	Jason Hopkins
University of Texas at Austin	Lance Manuel	
Vestas North America	Trevor Taylor	John Eggers
WSB-Hawaii	Warren Bollmeier	

ACP Offshore Wind Subcommittee members, at the time the standard was approved:

Company Name	Name
American Bureau of Shipping	Lars Samuelsson
Avangrid Renewables	Christopher Morris
Bureau of Ocean Energy Management	Sid Falk
Bureau of Ocean Energy Management	Angel McCoy
Bureau of Ocean Energy Management	Daniel O'Connell
Bureau of Safety and Environmental Enforcement	John Cushing
Bureau of Safety and Environmental Enforcement	Cheri Hunter
Bureau of Safety and Environmental Enforcement	Christy Lan
Bureau of Safety and Environmental Enforcement	Christopher Oliver
Cable Materials Inc.	Richard Ellis
Cathie	Neil Dyer
Cathie	Ismael Torres
COWI North America Inc.	Ting Sie Chui
DNV	Graham Cranston
DNV	Andreas Jensen
DNV	Watsamon Sahasakkul
EAPC Wind Energy	Robert Sherwin
EDP Renewables North America LLC	William Follett
Energy Challenges LLC	Felix Morales Florez
Equinor	Leif Delp
Excipio Energy Inc.	Georg Engelmann
Excipio Energy Inc.	Roy Robinson
ExxonMobil	Puneet Agarwal
Fugro USA Marine Inc.	Daniel Doolittle
Fugro USA Marine Inc.	Rosemary Smith
GE Renewable Energy	Albert Fisas
GE Renewable Energy	Edward McComb
GE Renewable Energy	Ben Palethorpe
GE Renewable Energy	Hongbiao Song

GE Renewable Energy	Derek Stilwell
Global Maritime	Gareth Ellery
GR8 GEO	Jacob Chacko
GZA GeoEnvironmental Inc.	Wayne Cobleigh
HDR	Omid Abdi
Hitachi Energy	Hugo Avila
Hitachi Energy	Steven Kunsman
ISC Consulting Engineers A/S	Torben Lokkegaard
ISC Consulting Engineers A/S	Anders Thomsen
KBR	Ching-Hsiang Chen
McNiff Light Industry	Brian McNiff
National Renewable Energy Laboratory	Mary M. Hallisey
National Renewable Energy Laboratory	Walt Musial
National Renewable Energy Laboratory	Jeroen van Dam
New Bedford Port Authority	Barbara Stone
NGI - Norwegian Geotechnical Institute	Zack Westgate
NKT Inc.	Robert Hobson
Northland Power	Mathieu Guinard
Ørsted Wind Power North America LLC	Elizabeth Andrews
Ørsted Wind Power A/S (Denmark)	Claus Fridtjof Christensen
Ørsted Wind Power North America LLC	Simon Hayes
Ørsted Wind Power A/S (Denmark)	Rasmus A. Olsen
Ørsted Wind Power North America LLC	Sarah Wootton
Pelastar	William Hurley
Principle Power Inc.	Alexia Aubault
Rhode Island Commerce Corporation	David Ciochetto
Saint James Marine LLC	Michael J Saint James
Semco Maritime A/S	Tommy Flindt
Semco Maritime A/S	Soren K. Gundersen
Semco Maritime A/S	Lars Humlebaek
Sevan SSP	Nico Vandenworm
Shell New Energies	Rain Byars
Shell	Heather Cousson
Siemens Gamesa Renewable Energy	Jeroen Bongers
Siemens Gamesa Renewable Energy	Kevin Pearce
Societe Generale	Chris Moscardelli
Spire Engineering Services LLC	Robert Sheppard

SSAB Americas	Miles Haberkorn
Stress Engineering Services Inc.	Dilip Maniar
Stress Engineering Services Inc.	William Walker
Trendsetter Engineering	Kim Mittendorf
University of Massachusetts Wind Energy Center	James F. Manwell
University of Texas at Austin	Lance Manuel
Ventolines U.S..	Lorry Wagner
Vestas Offshore Wind	Marten Eis
Vestas Offshore Wind	Amanda Schoen
Wood Thilsted	Hiram Mechling
Wood Thilsted	Matthew Palmer
Woods Hole Group Inc.	Rafael Ramos
WSP USA Inc.	Michael Drunsic

ACP Recommended Practice for Design, Deployment, and Operation of Submarine Cable in the United States (OCRP5) members, at the time the standard was approved:

ACP OCRP-5 Working Group Conveners

Role	Company Name	Name
Co-Chair	Burns and McDonnell	Darin Lawton
Co-Chair	Excipio Energy Inc.	Georg Engelmann
Co-Chair	NKT Inc.	Robert (Bob) Hobson

ACP OCRP-5 Team Members

Company Name	Name
Aegion Corporation	Tom Marti
Aegion Corporation	Martin Scanlan
Aegion Corporation	Bob Walker
AIS Ltd	Mike Sherman
American Clean Power Association	American Clean Power
American Clean Power Association	Sabrina Morelli
American Clean Power Association	Michele Myers-Mihelic
American Society of Mechanical Engineers	Luis Pulgarin
Americas Gleaned Seafood	Brick Wenzel

Anbaric Development Partners, LLC	Clarke Bruno
Anbaric Development Partners, LLC	Kevin Knobloch
Anbaric Development Partners, LLC	Bryan Sanderson
Aon plc	Daren Gretz
Avangrid Inc.	Jenny Briot
Avangrid Inc.	Tommi Virta
Black & Veatch	Justin Bardwell
Black & Veatch	Ali Barooee
BPP Cables	Duncan Sokolowski
Bureau of Ocean Energy Management	Jennifer Miller
Bureau of Safety and Environmental Enforcement	David Nedorostek
Bureau of Safety and Environmental Enforcement	Christopher Oliver
Bureau Veritas	Sergio Pereira
Bureau Veritas North America	Cristian son
Business Network for Offshore Wind	Elizabeth Barminski
Business Network for Offshore Wind	Amalie Doetsch
Cable Materials Inc	Richard Ellis
Caldwell Marine International	Gareth Roberts
Cathie Associates	Robin Comrie
Cathie Group	Gareth Ellis
Copenhagen Offshore Partners	Daniele Casale
DNV	Dayton Griffin
DNV	Cheryl Stahl
Durocher Marine Division of Kokosing Const Co Inc	Jack Breininger
EDF Renewables	francis chartrand
EDF Renewables	Riad El Andaloussi
Elbeone GmbHis	Jelte-Steffen Hipp
Energie Baden-Württemberg AG	Jonathan Howie
Engineering, Science, and Technology, Inc	John Morris
EnP Industrie	Bob Conners
Equinor ASA	Fabien Renaudin
Excipio Energy Inc.	Ian Grosvenor
Fugro	Tony Hodgson
Fugro	Proserpine Peralta
General Electric Company	Neil Kirby
Geotherm USA	Deepak Parmar
Geotherm USA	Nimesh Patel
Global Marine Group	Andrew Lloyd
gopower inc	Gaye Angela Ohanesian
gopower inc	Roger Dashner

Haley & Aldrich, Inc.	Carrie Layhee
Harbor Offshore, Inc.	Lester Garret
Helix Energy Solutions	John Davies
Iberdrola España, S.A.	Mikel Bosque Tapia
Invenergy LLC	DENIZ OZKAN
JDR Cable Systems	Mike Grimm
KEMA Labs a CESI Brand	Frank Cielo
Kiewit Corporation	Forest Rong
Leeward Renewable Energy, LLC	Ronald Grife
Lloyd's Register Group	Peter Huntley-Hawkins
Lloyd's Register Group	Euan Trousdale
Ls Cable America Inc.	Bill Wall
Marmon Utility LLC	Bruce Miller
Marmon Utility LLC	Mike Norton
National Renewable Energy Laboratory	Walt Musial
Netherlands Ministry of Foreign Affairs	Carter Craft
New York Power Authority	Girish Behal
Nexans S.A.	Elisabeth Gjolmesli
Nexans S.A.	Emmanuel Martin-Lauzer
Nexans S.A.	Maxime Toulotte
NKT Photonics division of Luna Innovations	Julio Toko
Norwegian Geotechnical Institute	Zack Westgate
Ocean Specialists, Inc.	Jose Troncoso
Ocean Specialists, Inc.	David Willoughby
Ocean Winds Ow Offshore S.L	Jarett Contino
Oceaneering International, Inc.	Luciana Abib
Oceaneering International, Inc.	Wesley Cort
Offshore Power LLC	Kyle Kingman
Offshore Wind Consultants	Jeff Fodiak
Omega Consulting Intl.	Jean-Luc Saquet
Onsite Hv Solutions Ag	Edward Gulski
Onsite Hv Solutions Ag	Rogier Jongen
Ørsted A/S	Henk-Jan Belderok
Ørsted A/S	Edward Jones
Ørsted A/S	Rasmus Olsen
Ørsted A/S	Kristen Trudell
Ørsted A/S	Sarah Wootton
Osbit Ltd	Robbie Blakeman
Osbit Ltd	Scott Gartshore
Pattern Energy Group LP	Michael Edds

Paulus, Sokolowski and Sartor, LLC	Megan Hayes
PFISTERER Holding AG	Peter Mueller
PFISTERER Holding AG	Mathew Nadakal
PFISTERER Holding AG	Peter Traber
Power Delivery Consultants, Inc.	RACHEL MOSIER
Power Delivery Consultants, Inc.	Peter Tirinzoni
Power Delivery Solutions, Inc.	Alfred Mendelsohn
POWER Engineers, Inc.	Dennis Johnson
POWER Engineers, Inc.	Steve Walker
Principle Power Inc.	HACHAN JEONG
Red Ensign Solutions	Andy Readyhough
Red Penguin Marine	Chris Sturgeon
Rhode Island Commerce	Jamie Buck
RPS Group plc	Sitara Baboolal
RSCC Wire & Cable LLC	Damian Billeaudeau
RUTE Foundation Systems, Inc	Evelyn Hunsberger
Scapa Group Ltd	Simon Terry
SeaRoc Group Ltd	Neil Pittam
Shell USA Inc.	Thiago Freire de Carvalho
Shell USA Inc.	Tim Reiher
Siemens AG	Kevin Pearce
Synaptec Ltd	Saul Matthews
TechnipFMC	George Parayil Tharakan III
Tetra Tech, Inc.	Ryan Earley
Tetra Tech, Inc.	Tracey Evers
Tetra Tech, Inc.	Nicholas Welz
Tilman Solutions LLC	Ian Griffiths
Underwriters Laboratories	Eric Bulington
Underwriters Laboratories	Paul Knapp
Underwriters Laboratories	Kai Zhou
United Brotherhood of Carpenters	Dan Kuhs
Whitman Consulting Group	Joel Whitman

ACKNOWLEDGEMENTS

The conveners, authors, and contributors to these recommended practice (RP) documents would like to thank the standards development organizations, organizers, sponsors, and the leadership team that collectively helped make these U.S. guidelines possible.

The most important part of this U.S. offshore wind standards development effort, the expert technical information that was shared and documented in these RPs, was provided through time and effort from over 300 volunteers and the many dozens of organizations that supported their efforts. However, additional appreciation is extended towards those organizations that provided the resources that enabled the working groups to assemble and these documents to be written independently, following American National Standards (ANS) process, while maintaining a strong and consistent organizational and administrative structure throughout the three-year process.

ACP Offshore Wind Subcommittee Members – We would like to extend our extreme gratitude to the general membership of the ACP Offshore Wind Subcommittee, a subcommittee under the ACP Wind Technical Standards Committee. The subcommittee was responsible for providing technical input and advice on the draft documents and advising on future directions. Each draft was reviewed by the subcommittee members prior to formal reviews that were conducted as part of the ACP/ANSI review process.

Working Group Chairs - We would also like to recognize the chairs of each of the working groups who volunteered their time to ensure each of the documents was published on time and with high quality. The chairs organized and edited their respective recommended practices documents, but also served as members of the ACP Offshore Wind Subcommittee. We are extremely grateful to the following individuals who devoted their time and effort to make these RPs possible:

Rain Byars, Shell New Energies (Working Group 1)

Graham Cranston, DNV (Working Group 1)

Lars Samuelsson, ABS (Working Group 2)

Leif Delp, Equinor (Working Group 2)

Michael Drunsic, WSP (Working Group 3)

Lorry Wagner, Ventolines U.S. (Working Group 3)

Matt Palmer, Wood Thilsted (Working Group 4)

Mathieu Guinard, Atkins Global (Working Group 4)

Georg Engelmann, Excipio Energy, Inc (Working Group 5)

Bob Hobson, NKT HV Cables AB (Working Group 5)

FOREWORD AND BACKGROUND

The Foreword and Background sections are included with this document for information purposes only and are not part of the ANSI/ACP OFFSHORE COMPLIANCE RECOMMENDED PRACTICE 2022 Recommended Practice for Design, Deployment, and Operation of Submarine Cable in the United States (OCRP5).

Foreword

The regulatory framework for the U.S. offshore wind industry has been under development for well over a decade but the first commercial projects are just making their way through the process now. In 2005, the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE)[1] were given authority, under the Energy Policy Act of 2005 (EPAct 2005), to grant leases on the Outer Continental Shelf (OCS) for offshore renewables and to promulgate any necessary regulations needed to ensure safe and orderly deployments. In 2009, BOEM published 30 CFR 585 "Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf", which are the first federal regulations governing the development of offshore wind facilities. It outlines a process spanning a typical offshore wind project (cradle to grave), from competitive leasing of the OCS and gaining site control, to permitting, commercial operations planning, facility design, commissioning, operations and inspection, all the way through decommissioning

. In the initial version of the 30 CFR 585 regulation, no specific standards are incorporated by reference. The regulation requires "best practices" be used, with the intent that best practices would eventually evolve from industry experience as it matured.

To that end, from 2009 to 2012, the U.S. offshore wind industry, in collaboration with BOEM, the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy (DOE), and the American Wind Energy Association (AWEA), developed a roadmap from existing standards to facilitate the definition of "best practices", which was titled *AWEA Offshore Compliance Recommended Practice (OCRP) 2012*. Over 50 members of the

---

[1] At the time EPAct 2005 was passed, BOEM and BSEE were under the name Minerals Management Service (MMS)

offshore wind industry participated in the development of *AWEA OCRP 2012* which covers all aspects of fixed-bottom offshore wind facility development, starting with the design phase through to decommissioning. It refers to over 100 standards, guidelines, and technical specifications. After its publication in October 2012, it became the *de facto* reference for offshore wind development in the United States and has been used as an informative framework for regulators, developers, and certified verification agents.

However, for several reasons, *AWEA OCRP 2012* no longer adequately addresses the regulatory requirements for BOEM/BSEE and the offshore wind development community. First, when it was written, the formal process for review and approval by the American National Standards Institute (ANSI) had not yet been adopted by ACP. This formal approval process is critical for the acceptance of standards by the regulators because U.S. ANSI-approved consensus standards and guidelines have vital procedural safeguards that allow them to be adopted by developers to guide project design and approval, referenced by BOEM in future revisions of 30 CFR 585 or, if appropriate, they can be explicitly quoted by BOEM/BSEE in 30 CFR 585 or other regulations. In addition to this important step, missing but needed to attain credibility in the regulatory process, the scope of *AWEA OCRP 2012* was too narrow and did not cover key aspects of the current U.S. industry. Floating foundation systems are explicitly not covered even though the industry is rapidly moving toward the commercialization of floating wind. Also, the complexity of collecting, processing, validating, and applying metocean data was not addressed. Similarly, requirements for geotechnical and geophysical data collection were not addressed at all, despite the wide range of site conditions across the potential U.S. lease areas and number of substructure variants. In addition, the treatment of subsea high voltage cables was very light in *AWEA OCRP 2012* and did not adequately recognize the unique challenges associated with the use of subsea cables that the industry is currently facing in Europe. Finally, in addition to the noted missing elements in *AWEA OCRP 2012*, the document is over ten years old and does not adequately reflect the experience gained through the installation of over 50 gigawatts of offshore wind globally, and the extensive U.S. project development experience that has occurred since it was written.

In December 2016, BOEM requested that ACP establish a new initiative to update the existing *AWEA OCRP 2012* document to address the above concerns. In September 2017, the ACP Wind Standards Committee voted to approve the formation of an offshore wind subcommittee to oversee the development of this initiative. This subcommittee was formed under the leadership of Walt Musial, Principal Engineer at NREL, and held its inaugural meeting on October 23, 2017. At that meeting, five working groups were formed to address the *AWEA OCRP 2012* deficiencies. These working groups include:

OCRP 1 - Working Group 1 - ACP Offshore Compliance Recommended Practices (OCRP) Edition 2 under the leadership of Rain Byars and Graham Cranston.

OCRP 2 - Working Group 2 - ACP U.S. Floating Wind Systems Recommended Practices under the leadership of Lars Samuelsson and Leif Delp.

OCRP 3 - Working Group 3 - ACP U.S. Offshore Wind Metocean Conditions Characterization Recommended Practices under the leadership of Mike Drunsic and Lorry Wagner.

OCRP 4 - Working Group 4 - ACP U.S. Recommended Practices for Geotechnical and Geophysical Investigations and Design under the leadership of Matt Palmer and Mathieu Guinard.

OCRP 5 - Working Group 5 - ACP Recommended Practices for Submarine Cables under the leadership of Georg Engelman, Bob Hobson, and Darin Lawton.

These dedicated and qualified industry conveners each assembled a diverse group of subject matter experts in their respective working groups. All told, over 350 members of the U.S. offshore wind industry participated in this initiative.

Initially, the working groups developed a coordinated set of work scopes that were approved through the ANSI process, and each worked independently to develop a recommended practice (RP) document following the ACP/ANSI rules. Each RP provides a roadmap for U.S. offshore wind development in its respective area with a view toward adding transparency and consistency to the regulatory approval process which can provide benefits to developers, regulators, and the general public.

All the working groups collectively, assembled face-to-face at semi-annual meetings throughout a five-year period from 2018 through 2022 where issues with harmonization, consistency, potential conflicts, and gaps were identified and resolved. Together, these working groups have developed a comprehensive set of consensus-based RPs to guide the safe and orderly deployment of offshore wind energy in the United States. These nationally focused RP documents account for the unique offshore conditions on the U.S. OCS but they also apply to potential installations in state waterways (e.g.,Great Lakes). They provide reasonable requirements for commercial offshore development covering a range of project development activities including project design, construction and deployment practices, operation, safety, inspection and decommissioning, while anticipating the new and evolving nature of the offshore wind technology. This suite of offshore RPs will help clarify the requirements for developers beyond what was provided by *AWEA OCRP 2012* and enable BOEM/BSEE to adopt better requirements that reflect industry best practices.

Although these five RP documents were written independently by their respective working groups, a significant effort was made to coordinate the technical interfaces. As such, they are intended to be used as a set. The governing RP was written by Working Group 1 - ACP Offshore Compliance Recommended Practices (OCRP) Edition 2. This document supersedes original *AWEA OCRP 2012* document and, in several areas, defers directly to the companion RP documents from Working Groups 2 through 5. Similarly, the companion RP documents refer to the governing OCRP-1 document.

It is the expectation of all who participated in this important standards development process that this comprehensive set of RP documents will clarify the complexities of offshore wind development in the United States while providing clarity for all stakeholders and, in doing so, will help lower offshore wind energy costs and increase worker safety for the public good.

1 CONTENTS

1 INTRODUCTION

Over the past two decades, the onshore (land-based) wind energy market has been growing at an exponential pace in the United States. By contrast, US offshore wind has only installed seven (7) wind turbines for a total of 42 MW of generation. Around the world and especially in Europe, offshore wind has been growing exponentially. Hornsea 1 is the first 1 GW offshore wind farm commissioned with many more offshore wind farms in the process of being built. The first offshore wind farm installed in Europe was recently decommissioned and removed from the ocean after 27 years of service. The guidelines and standards currently adopted in the United States were based on the US onshore wind farms that are limited in size to approximately 3 MW turbines and a maximum export cable voltage of 35 kV. The existing US offshore wind recommended practice (RP) required revision to incorporate the best and proven worldwide practices of the offshore wind market and aid in the future design, construction, operation, maintenance, and decommissioning of U.S. offshore wind systems. In addition, the existing guidelines were not equipped to provide sufficient resources and data for permitting agencies such as the Bureau of Offshore Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) to perform a detailed evaluation for upcoming offshore wind projects.

The goal of these working groups is to update or revise the Offshore Compliance Recommended Practice (OCRP) that was released in 2012 and make it current with updated best practices from existing worldwide industry standards, new technologies, and new means and methods used since the release of the OCRP 2012 document.

This document is specifically written to cover all subjects and topics associated with Submarine Cables. Offshore wind farm submarine cable systems are primarily composed of array cable and export cable systems. Array cable systems are used to move the power generated by the wind turbines back to a collector substation oftentimes referred to as the Offshore Sub Station (OSS) or Offshore Service Platform (OSP). Export cables are used to move the power from the offshore collector substation to the land-based transmission grid.

This RP document represents the best collation of guidance and information available in a U.S. context, for the application of high voltage (HV) submarine cables. In addition, given that this RP document has been written to align with the U.S. Title 30 of the Code of Federal Regulations (CFR), Part 585 “RENEWABLE ENERGY AND ALTERNATE USES OF EXISTING FACILITIES ON THE OUTER CONTINENTAL SHELF”, parts of this document may be relevant to other ocean energy technologies such as wave energy conversion, tidal energy conversion, thermal energy conversion, solar energy conversion, or other energy conversion concepts, in addition to the offshore wind energy conversion, but a full treatment of those technologies was beyond the scope of this working group. The applicability to these other methods of generation may not covered by BOEM and must be determined by the appropriate regulatory authority having jurisdiction.

From the perspective of this recommended practice (OCRP-5) related to the use of the HV submarine cable itself, the specific source of electrical power being conveyed is not necessarily relevant, however the cable design processes from planning through decommissioning can be seen as highly similar if not identical to that of offshore wind energy deployment. In addition, the applicable domains, as noted elsewhere are not only offshore Outer Continental Shelf (OCS) Federal Waters, but nearshore state waters, ports, bays, estuaries, river deltas, riverbeds, inland lakes, coastal, inter/intra-coastal and inland waterways. Although noted functionalities in the context of the offshore wind application were as array and export cable system, this RP is likewise relevant for submarine transmission and distribution infrastructure, as functional and performance requirements would be the same.

Typically, the cable system that connects all the components of an offshore wind farm represent between 10 and 15% of the capital expenditure (CAPEX) of an offshore wind farm. The proper design of the cable systems with specific data sets such as those acquired via geotechnical and geophysical surveys is of significant importance. Front-end loading the project with such information is vital when designing an offshore windfarm given its criticality for informing early design decisions. Lack of timely data availability can be cited as a root cause in past export cable system failure events where the entire offshore wind farm production was lost until the export cable could be repaired. Thus, the initial 10-15% of an offshore wind development CAPEX cost can shut down the entire revenue stream from the wind farm for months or longer undermining the true economic viability of both the development opportunity as well as shareholder and stakeholder confidence in the application of the technology. The entire wind farm asset becomes stranded, and this aspect is often overlooked by the developers of the wind farm. If designed and installed properly, submarine cable systems will provide decades of service with little or no maintenance.

When a cable system is not designed properly and installed correctly, submarine cable systems can be costly and a time-consuming asset to repair or replace when considering the lost revenue of the entire wind farm. There are ways to reduce the cost of a submarine cable system and one of the most cost-effective efforts is to start early in the planning of the cable system. In the past, cable systems have not been typically considered until the latter stages of the design cycle which has led to designs based on overly conservative assumptions that lead to a costlier cable construction and may still not meet the full requirement of the project.

Wind farms are projected to increase in size and distance from the grid connection. At the time this document was written, the demands on the size and voltage of the 3-core HVAC cables are pushing the currently available manufacturing limits of what is commercially available. HVDC cable systems can accommodate higher loads and longer distances, but at additional cost and time (minimum 3 years for the converters alone) constraints.

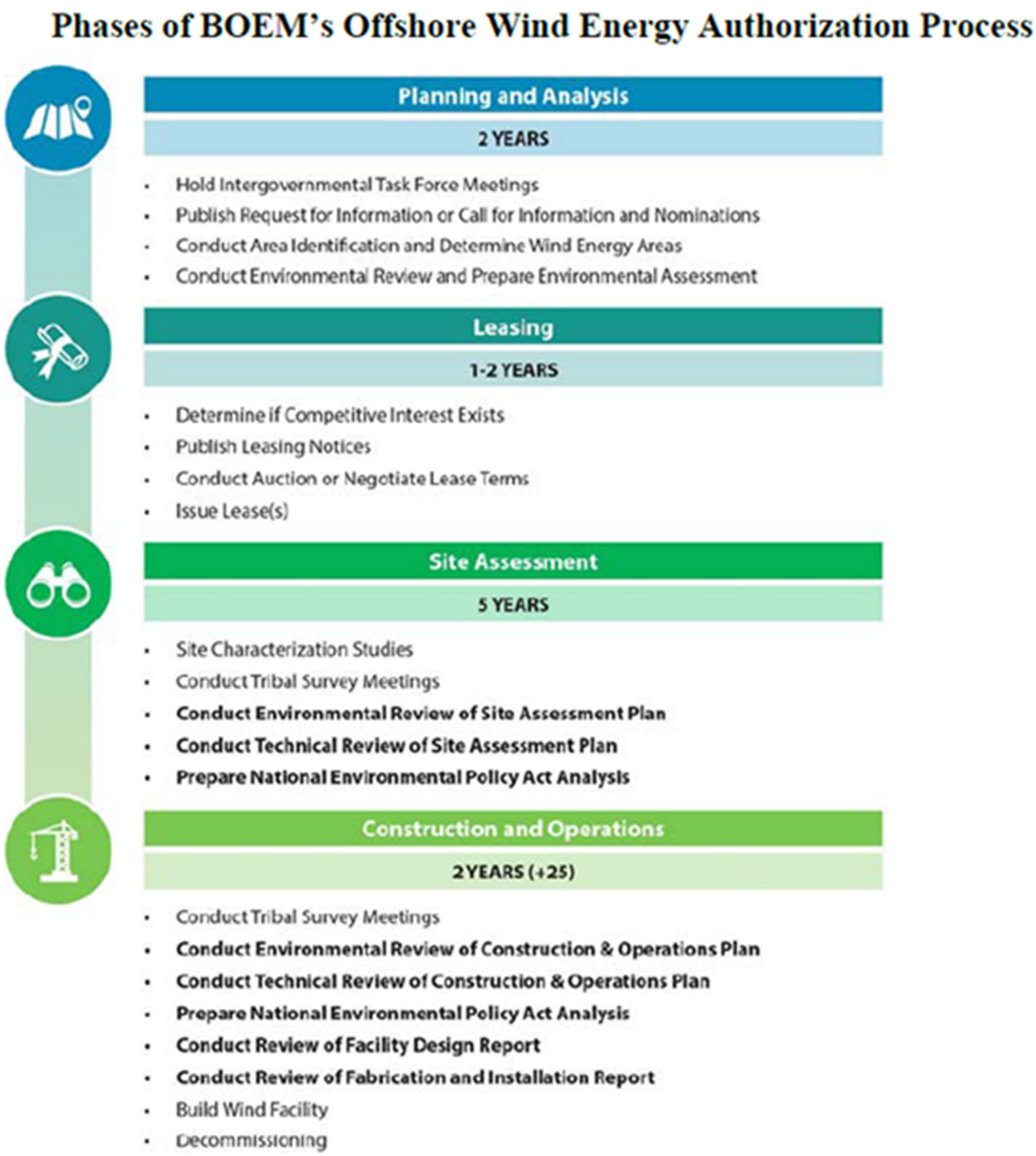
The old saying that the strength of a chain is only as strong as its weakest link also applies to a cable system. One thermally limiting location, or “hot spot”, along the cable route could lead to its premature failure. Having accurate soil thermal resistivity (TR) values along the export cable system alignment(s) is one of the primary data sets needed for a good cable design and must be determined by the developer as soon as possible in the design cycle. One thermally limiting location, or "hot spot", along the cable route could lead to its premature failure. A desktop analysis for the TR values for the export cable system alignment(s) is a very risky option which could lead to costly delays and replacements, especially if measured TR data is worse than originally estimated resulting in increasing the conductor size, or worse forcing the owner to reduce the rating of the wind park. Performing a TR survey early is extremely beneficial because it drives the design of the cable system and identifies any potential design flaws that could become project catastrophes when construction and operation deadlines are accounted for. In addition to accurate TR values, a number of other factors impact the export cable design from ocean floor conditions to local policy and port regulations. These other factors include, but are not limited to, the following:

- Technology selection (i.e.,HVAC or HVDC, Wind Turbine Generator model)
- Soil temperature
- Seabed morphology
- Seabed mobility (i.e.,the influence of waves and tides on sediment)
- Required cable burial depths
- Port installation requirements
- Socio-economic activities (i.e.,fishing techniques, etc.)
- Cable protection measures
- Etc.

There are many good financial reasons to have the electrical connection (export cable) to the OSS in place when the substation is ready to be installed on the offshore platform. From initial conception to installing cables in the ocean can easily take two to four years, which in many cases is the time frame to construct and install the wind farm offshore substation and foundation.

Below are the approximate time frames for an offshore export cable system independent of the time required for permits. This assumes having the cable system manufacturing and installation resources (slots) available. This timeline does not include the calendar limits on installation time of year due to weather conditions which can add significant additional time to the schedule if installation has to be shifted due to weather. For array cables a similar time frame can be expected.

Table 1 Regulatory phase of a wind farm



https://www.boem.gov/sites/default/files/documents/about-boem/2022-BOEM-Greenbook.pdf

In this document the reader should find a "road map" to existing best practice standards that will provide definitive detail on the recommended practice for design, deployment, and operation of submarine cable in the United States.

2 GENERAL INTRODUCTION

2.1 Objectives of the RP

The objective of this document is to provide a “road map” to the existing and proven best practices and published standards that will provide definitive detail on the design and installation of subsea cables for offshore wind energy systems in the United States, allowing the user to identify the appropriate standard(s) having details about the subject heading.

2.2 Functional Requirements

This standard applies to submarine cables both AC and DC with voltage classes rated 35 kV and above. To ensure sufficient flexibility, allowing for advancing the state of the art, this document was constructed around the international approach using functional and performance requirements, taking a system perspective as opposed to the component specific approach. In principle, the working group has adopted the international philosophy of applying functional requirements in the interest of preserving “room to grow” for the industry

2.3 Applicable Codes, Standards, Recommended Practices and Guidelines

All codes and standards referenced in this document are assumed to be latest edition unless specifically stated otherwise. Please see Appendix A.1 for a complete listing of externally referenced standards including titles. Additionally, language (i.e., “shall”, “should”, etc.) provided in referenced standards is only used for recommendations and does not constitute direct requirements.

2.3.1 Normative References

Normative references can be found in Appendix A, B, and C, attached which contains: Appendix A lists alphabetically all normative references directly referenced in this document. Appendix B lists alphabetically all references that reference the documents in Appendix A or references that were replaced by the documents in Appendix A. Appendix C lists alphabetically all references related to submarine cables that are potentially worthwhile for the user.

2.3.1.1 International Electrotechnical Commission, Standard References

Throughout this document reference is made to IEC standards. The following information should be noted and considered relating to the reference of these standards and their use or non-use as it relates to this document.

Adoption of IEC standards by any country, whether it is a member of the IEC or not, is entirely voluntary. The standard may be adopted in full or with regional or national differences depending on the needs and requirements of the adopting national committees. IEC standards are considered consensus documents and represent a common viewpoint of those parties concerned with its provisions, namely producers, users, consumers, and general interest groups. IEC's International Standards are developed by international consensus among the IEC's members (National Committees). Any member of the IEC may participate in the preparatory work of an International Standard, and any international, governmental, and non-governmental organization liaising with the IEC also participates in this preparation.

This RP document does not make any specific reference to any country's nationally adopted version of an IEC standard, as such documents have potentially been developed by that adopting countries national committees and may reflect necessary requirements for that country that would not apply inside the United States.

2.3.1.2 International Council on Large Electric Systems, Technical Brochure References

The user of this document should note that the CIGRE TB (Technical Bulletins) are not standards but are often used as the precursor documents to IEC standards for topics or products where such a standard does not already exist and is deemed necessary. They are written by a group of multi country subject matter technical experts on a subject that is either new or in the process of significant change in an attempt to gather the most up to date, best available, and technically factual information on a given subject. Once completed these documents are published by CIGRE as a TB and made available to CIGRE members and to the public through the CIGRE website. The CIGRE documents referenced in this RP document have been referenced by the working group responsible for creation of this document as they represent the best available information and are referenced in absence of nationally or internationally published consensus standards.

2.4 Abbreviations, Definitions and Acronyms

2.4.1 Abbreviations and Acronyms

AC	Alternating Current
AEIC	Association of Edison Illuminating Companies
AIS	Air-Insulated Switchgear
AIT	Air-Insulated Termination
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
API	American Petroleum Institute

ASTM	American Society of Testing Materials
ATS	Acceptance Testing Specifications
AWEA	American Wind Energy Association
BOEM	Bureau of Ocean Energy Management
BS	British Standard
BSEE	Bureau of Safety and Environmental Enforcement
CAPEX	Capital Expenses
CBRA	Cable Burial Risk Assessment
CFE	Controlled Flow Excavation
CFR	Code of Federal Regulations
CIGRE	Conseil International des Grands Réseaux Électriques (International Council for Large Electric Systems)
CLV	Cable Lay Vessel
COP	Construction Operation Plan
CSA	Canadian Standards Association
CT	The Carbon Trust
CVA	Certified Verification Agent
CZMA	Coastal Zone Management Act
DAS/DVS	Distributed Acoustic/Vibration Sensing
DC	Direct Current
DNV GL	Det Norske Veritas – Germanischer Lloyd
DOB	Depth of Burial (change over time relative to as-built)
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DSS	Distributed Strain Sensing
DTS	Distributed Temperature Sensing
EMSR	Renewables Electrical and Mechanical Safety Rules (Avangrid internal)
EPRI	Electric Power Research Institute
EMC	ElectroMagnetic Compatibility
EMF	Electro-magnetic field
EN	European Norm
EQT	Extension of Qualification Test
FAT	Factory Acceptance Test
FDR	Facilities Design Report
FERC	The Federal Energy Regulatory Commission
FIR	Facilities Installation Report

FO	Fiber Optic
GAP	General Activities Plan
GFCI	Ground Fault Circuit Interrupter
GIS	Gas-Insulated Switchgear
GW	GigaWatt
HDD	Horizontally Directionally Drilled
HVAC	High-Voltage Alternating Current
HVDC	High-Voltage Direct Current
ICEA	Insulated Cable Engineers Association
ICPC	International Cable Protection Committee
IEC	International Electrotechnical Commission
IECRE	IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications
IEEE	Institute of Electrical and Electronics Engineers
IHO	International Hydrographic Organization
IMCA	International Marine Contractors Association
IP	Ingress Protection
ISO	International Organization for Standardization
ISO	Independent System Operator
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
ITP	Inspection and Test Plan
kV	kiloVolt
LCOE	Levelized Cost of Energy
LWP	Longitudinal Water Penetration
MBR	Minimum Bending Radius
MEC	Munitions and Explosives of Concern
MFE	Mass Flow Excavation
MW	MegaWatt
NASCA	North American Submarine Cable Association
NEC	National Electric Code (U.S.)
NESC	National Electrical Safety Code
NERC	North American Electrical Reliability Corporation
NETA	International Electrical Testing Association
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association (United States)
NOAA	National Oceanic and Atmospheric Administration

NORSOK	Norsk Sokkels Konkurranseposisjon
NREL	National Renewable Energy Laboratory (United States)
NRTL	Nationally Recognized Testing Laboratory (U.S. Department of Labor/Occupational Safety and Health Administration)
O&M	Operations and Maintenance
OCRP	Offshore Compliance Recommended Practices
OCS	Outer-Continental Shelf
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration (U.S. Department of Labor)
OSIG	Offshore Site Investigation and Geotechnics Committee
OSS	Offshore Substation
OSP	Offshore Substation Platform
OTDR	Optical Time Domain Reflectometry
PD	Partial Discharge
PE	Professional Engineer (State specific registration)
PES	Power & Energy Society (part of IEEE)
POI	Point of Interconnection
PP	Polypropylene
PPE	Personal Protective Equipment
PQT	Pre-qualification Test
PSCCC	Technical Committee on Power System Communications and Cybersecurity (part of IEEE PES)
RCD	Residual Current Device
ROV	Remote Operated Vehicle
ROW	Right of Way
RSSI	Renewables System Safety Instructions
RWP	Radial Water Penetration
SAP	Superabsorbent Polymer
SDO	Standards Developing Organization
SMS	Safety Management System
SWP	Sidewall Pressure
S0	IEEE PES PSCCC Cybersecurity Subcommittee
TDR	Time Domain Reflectometry
TR	Thermal Resistivity
TT	Type Test

U_0, U, U_m	Phase-to-Ground, Phase-to-Phase, and Highest Voltage Under Normal Operating Conditions[2]
U_m	Highest Rated Voltage for Equipment
UL	Underwriters Laboratories
UPS	Uninterruptable Power Supplies
USCG	United States Coast Guard
UXO	Unexploded Ordinance
V	Volt
VAC	Volt Alternating Current
VDC	Volt Direct Current
WBP	Water Blocking Powder
WBT	Water Blocking Tape
WBY	Water Blocking Yarn
WTG	Wind Turbine Generator
WROV	Work-equipped remotely operated underwater vehicle

[2] Reference IEC 60183.

2.4.2 Normative Naming Conventions Between Standard Organization Terminology

The following list presents the commonly used terminology for certain components of a cable or cable system that may be referred to differently in international standards than the term commonly used in North America. The list shows the North American term first and then the international term. This section is intended to make it easier for the reader to associate different terms used in standards between North America and internationally:

- Conductor shield - may be referred to as a conductor screen.
- Insulation shield - may be referred to as an insulation screen.
- Jacket - may be referred to as an over sheath or non-metallic sheath.
- Metallic shielding - may be referred to as a metal screen
- Concentric neutral - may be referred to as a metal screen
- Production tests - may be referred to as Routine and/or Sample tests
- Qualification tests - may be referred to as Type Tests, pre-qualification tests and other design tests
- Cable ampacity calculations - may be referred to as cable dimensioning, sizing, or rating
- Cable clamps - may be referred to as cable cleats
- Contractor commission testing - may be referred to as after-installation testing
- Owner commission testing - refers to overall system testing
- Joints - may be referred to as splices throughout document
- Cable Bonding - may be referred to as grounding or earthing
- AIS - sometimes called AIT when it is terminating on a pole versus a substation or switchgear

2.4.3 Definitions

Blocked conductor: A stranded conductor whose interstices are filled with one or more materials that prevents the migration of moisture longitudinally through such interstices. Water blocking powders, water blocking tapes and yarns containing superabsorbent materials, are commonly used to provide “dynamic” water blocking functionality. Flexible, semi-conducting thermoplastic strand fill compounds can be used as a means of providing a “static” water blocking functionality. Often, conductor water blocking includes the use of both the dynamic superabsorbent and the static thermoplastic materials.

Customer: The party that is paying for the services to be performed and material to be supplied. This party is sometimes referred to as Employer.

Contractor: The party or parties that are supplying the materials or services and are contractually obligated to the Customer or Employer to deliver the materials or services specified in the contract. This party is sometimes referred to as a supplier. A contractor may include any and all of the following parties: Cable supplier, Cable installer, Accessories supplier, testing company, Owners Engineer, CVA to name just a few examples.

Longitudinal water blocking: Term used to describe a cable design that prevents the longitudinal flow of water, moisture or contaminates along the cable core. The term can refer to the materials that provide a method for blocking the longitudinal ingress of water, moisture or contaminates along the cable core, concentric neutral, metallic shield, screen, armoring or other cable interstices, during cable manufacturing as well as, during cable transport, storage, installation, splicing, termination or from a defect or sheath damage after installation.

Moisture-impervious cables: These are cables designed to prevent both the radial and longitudinal entrance of moisture into the cable core and to prevent the longitudinal migration of moisture down the core.

Non-woven water-blocking tapes: Cable tapes consisting of one or more non-woven webs plus other materials needed to maintain mechanical integrity. Super absorbing powders are locked into the non-woven tapes to provide water blocking capabilities to the tape. Depending on the location of such tapes within a cable, they may also provide cushioning to absorb expansion of the cable core. They may provide a way of binding the cable elements. They may be non-conducting or semi-conducting. Also, the tape may be called a water-swellable tape.

Radial-moisture barrier: A metallic layer beneath the sheath that effectively blocks the transmission of moisture into the cable from a radial direction.

Repair Bight: The slack loop that is created as a result of recovering a cable from the seabed onboard a vessel for purpose of repair. The surface recovery imparts the shape of a double catenary, or “omega-joint” in the cable profile, which is then re-laid to the seabed with the induced repair bight lying lateral to the initial cable centerline.

Strand-blocking: A method for filling the strand interstices of the conductor wires with a material that will block the movement of moisture and contaminants into and along the stranded conductors via capillary action. Two common technologies for strand-blocking are strand filling compounds and/or swellable water blocking materials. Either technology is applied to the strand during each stage of the stranding process to ensure the conductor is completely blocked. In many cases, both technologies are utilized in the same conductor.

Strand filling compound: A flexible, hydrophobic, semi-conducting, thermoplastic polymer that is injected into the strand interstices of the conductor wires during the stranding process using heat and pressure. The strand filling compound is intended to completely fill the space between the wire strands, eliminating any channel for water ingress.

Swellable water-blocking material: A SAP in powder or fiber or liquid form that swells when in contact with water and forms a gel to block the longitudinal ingress of moisture in a cable. The SAP can be used as a standalone product, or as a component of another substrate, such as a nonwoven tape, a multifilament yarn, hot melt adhesive, or other “carriers”.

Shield / Screen: In North America it is common to refer to these layers as shields instead of screens.

Water-blocking yarns: A spun yarn formed with a combination of polymeric fibers, super absorbent polymers, and longitudinal or helical filament reinforcement.

Woven water-blocking tapes: A woven synthetic web with a coating of swellable powder on one or both sides. Woven water-blocking tapes are commonly used as a peripheral wrap over the conductor and therefore must also function as a barrier against penetration of the extruded conductor screen into the free space between the stranded conductor wires.

2.4.4 Normative Terms Used in the Cable Industry

Electropedia is produced by the IEC, an organization that prepares and publishes International Standards for all electrical, electronic, and related technologies collectively known as “electrotechnology.”Electropedia (also known as the "IEV Online") contains all the terms and definitions in the International Electrotechnical Vocabulary or IEV which is published also as a set of publications in the IEC 60050 series.

To search the IEC Electropedia, go to:

http://www.electropedia.org/

IEEE 100 “The Authoritative Dictionary of IEEE Standards Terms”

The IEEE 100 includes nearly 35,000 technical terms and definitions from over 800 standards covering areas such as power and energy, communications, information technology, and transportation systems. In addition to an extensive list of widely used acronyms and abbreviations, this new edition also contains detailed abstracts of each term’s associated standard(s). The definitions are augmented by a combination of information, including:

- Preferred and popular usage of each term
- Variations in meanings among different technical specialties
- Cross-indexing to related works
- Key explanatory notes for further term clarification

The IEEE 100 document is available from the IEEE website for purchase.

3 ROUTE PLANNING AND PERMITTING

3.1 Constraints Study and Initial Route Development

The development of a subsea cable route is an iterative process, the aim of which is to determine the safest, most technically viable and most economic cable route possible.

A *Constraints Study* or *Cable Route Study* is an important Desktop Study that guides the initial phase of route development. The Study should harness all existing information that is available on the project site and identify data gaps that will inform subsequent stages of route investigation and development.

The Study will typically comprise not only of a written report but also of an initial model, known as a Ground Model, (discussed in detail in OCRP-4) where all geographical information system data is captured, to help create a 3D representation of the site conditions. All relevant geographical information system data will be imported in consistent horizontal and vertical datums of the same coordinate system, in accordance with the project reference system guidelines. The Ground Model will be developed further as the project progresses and additional data is gathered for the project.

Important factors to consider from the outset of route development are identified below. This is not an exhaustive list and project specific criteria must always be identified and captured in the Study. Furthermore, factors can vary in significance even within a project, depending on location (e.g., onshore, nearshore, offshore) and timescales (e.g., hours, days, seasons, years), and this must also be considered. As the project progresses towards the construction phase and cable protection requirements become more clearly defined, some of these criteria will be revisited to further refine the cable route(s) where possible.

Key considerations include (but are not limited to):

- Any confirmed fixed points e.g., grid connection point [see section 3.6], OSP or WTG locations, etc.
- Regulatory requirements [see sections 3.2 and 3.3] i.e., State, Federal, etc.
- Other seabed users [see section 3.4] including commercial operations e.g., fishing areas, shipping routes, anchorages, restricted areas, etc. with respect to target burial depths below proposed authorized depths.
- Existing and planned infrastructure e.g., subsea cables, pipelines, sea defense systems, etc.
- Bathymetry and seabed features (e.g., mobile bedforms, boulders, debris, etc.)
- Archaeology and wrecks
- Geology i.e., shallow soils, rock outcrops etc.
- Seismicity i.e., seabed stability

- Meteorological and oceanographic conditions, e.g., tides, currents, wind and wave regimes, ice etc.
- Natural Environment i.e., protected flora and fauna
- UXO risks

The output of the Study should include details such as the following:

- Basic route engineering recommendations including preliminary route position list
- Preliminary geographical information system ground model
- Understanding of the seabed and ground conditions
- Understanding of restricted and protected areas, exclusion zones and infrastructure crossings
- Feasible cable protection methods
- General survey requirements and recommendations (geophysical and geotechnical)
- Permit conditions or restrictions

Further guidance on cable route development is provided in the following documents:

- ICPC Recommendations 2 - Cable Routing and Reporting Criteria
- ICPC Recommendations 9 - Minimum Technical Requirements for a Desktop Study
- BSEE TAP Report Number 671, Offshore Electrical Cable Burial for Wind Farms: State of the Art, Standards and Guidance & Acceptable Burial Depths, Separation Distances and Sand Wave Effect.
- The Crown Estate, Export transmission cables for offshore renewable installations – Principles of cable routing and spacing.
- DNVGL-RP-0360 - Subsea Power Cables in Shallow Water
- DNVGL-ST-0359 - Subsea Power Cables for Wind Power Plants

3.2 State Permitting Guidelines

The National Coastal Zone Management Program works with coastal states and territories to address some of today's most pressing coastal issues, including climate change, ocean planning, and planning for energy facilities and development.

The program is a voluntary partnership between the federal government and U.S. coastal and Great Lakes states and territories authorized by the CZMA of 1972 to address national coastal issues. The program is administered by NOAA.

For the state specific permitting, the developer should consider engaging with at least the following agencies which cooperate with, or locally administer, the CZMA guidelines.

State	**Agency**
Alabama	Department of Conservation and Natural Resources
	Marine Resources Division
	Public Service Commission
Alaska	Department of Fish and Game
	Department of Natural Resources
	Regulatory Commission of Alaska
California	Coastal Commission
	Department of Fish and Wildlife
	Environmental Protection Agency
	Natural Resources Agency
	San Francisco Bay Conservation and Development Commission
	State Lands Commission
Connecticut	Council on Environmental Quality
	Department of Energy and Environmental Protection
	Siting Council
Delaware	Department of Natural Resources and Environmental Control

Florida	Department of Environmental Protection
	Department of State
	Fish and Wildlife Conservation Commission
	Florida Department of Agriculture and Consumer Services
	Siting Coordination Office
Georgia	Department of Natural Resources
	Environmental Finance Authority
	Public Services Commission
	State Properties Commission
Hawaii	Department of Business, Economic Development and Tourism
	Department of Health
	Department of Land and Natural Resources
	Office of Planning
	Public Utilities Commission
Illinois	Commerce Commission
	Department of Natural Resources
	Environmental Protection Agency
Indiana	Department of Environmental Management
	Department of Natural Resources

	Utility Regulatory Commission
Louisiana	Department of Environmental Quality
	Department of Natural Resources
	Department of Wildlife and Fisheries
	State Land Office
Maine	Department of Agriculture, Conservation, and Forestry
	Department of Environmental Protection
	Department of Marine Resources
	Land Use Regulation Commission
	Public Utilities Commission
Maryland	Department of the Environment
	Public Service Commission
Massachusetts	Department of Environmental Protection
	Department of Fish and Game
	Department of Public Utilities
	Energy Facilities Siting Board
	Executive Office of Energy and Environmental Affairs
Michigan	Department of Environment, Great Lakes & Energy

	Department of Environmental Quality
	Public Service Commission
Minnesota	Department of Natural Resources
	Pollution Control Agency
	Public Utility Commission
Mississippi	Department of Marine Resources
	Department of Wildlife, Fisheries, and Parks
	Secretary of State
New Hampshire	Department of Environmental Services
	Fish and Game Department
	Site Evaluation Committee
New Jersey	Department of Environmental Protection
New York	Board of Public Utilities
	Office of General Services
	State Department of Environmental Conservation
	State Public Service Commission
North Carolina	Department of Administration
	Department of Environment and Natural Resources
	Wildlife Resources Commission
Ohio	Department of Natural Resources

	Environmental Protection Agency
	Power Siting Board
Oregon	Department of Fish and Wildlife
	Department of Land Conservation and Development
	Department of State Lands Waterway Leasing
	Energy Facility Siting Council
Pennsylvania	Department of Conservation and Natural Resources
	Department of Environmental Protection
	Fish and Boat Commission
Rhode Island	Coastal Resources Management Council
	Department of Environmental Management
	Energy Facility Siting Board
South Carolina	Department of Health and Environmental Control
	Department of Natural Resources
	Public Utility Commission
Texas	Coastal Coordination Advisory Committee
	Commission on Environmental Quality
	General Land Office
	Parks and Wildlife Department

Virginia	Department of Environmental Quality
	Marine Resources Commission
	State Corporation Commission
Washington	Department of Ecology
	Energy Facility Site Evaluation Council
	State Department of Natural Resources
Wisconsin	Coastal Management Council
	Department of Administration
	Department of Natural Resources
	Public Service Commission
	Wind Siting Council

3.3 Federal Guidelines

BOEM is responsible for offshore renewable energy development in Federal waters. The program began in 2009, when the DOI announced the final regulations for the OCS Renewable Energy Program, which was authorized by the EPA. These regulations provide a framework for all of the activities needed to support production and transmission of renewable energy sources other than oil and natural gas.

BOEM is tasked with providing access to offshore wind development in lease areas and issuing right-of-way easements and grants for transmission cables. Generally, export cable routes are not highly considered during the Area Identification process as cable landing predictions can be highly speculative due to the amount of time it takes to identify an area, hold a lease sale, and begin project specific negotiations. However, BOEM does consider a potential lease area's proximity to onshore and offshore infrastructure and hazards, including project descriptions (design and installation parameters), feasibility analysis, and an assessment of site conditions and hazards. BOEM regulated offshore transmission cables are reviewed either as part of a COP or a GAP or as described respectively in 30 CFR 585.626 and 585.645. Final design, fabrication, and installation information is then provided as part of the FDR and FIR. Information provided in the FDR/FIR documents must be consistent with the approved COP or GAP and all associated terms and conditions. Fabrication and installation can begin after BOEM sends notification that the reports have been received and has no objections. If BOEM does not respond within 60 days, it is deemed BOEM has no objections.

BOEM produced guidance and studies that support offshore wind development and can be found on the BOEM website (www.boem.gov). The guidance and studies cover a wide range of subject matter topics including:

- Application and Leasing
- Information Requirements for Site Assessment Plans
- Information Requirements for Construction and Operations Plans
- Draft Design Envelope Guidance
- Providing Information on Fisheries Social and Economic Conditions for Renewable Energy Development on the Atlantic OCS, and
- Survey Guidelines

In addition, specific to submarine cable guidance and routing, BOEM recommends following ICPC guidelines (https://www.iscpc.org/publications/recommendations/) and early and often coordination on cable routing planning with both the DOD and NASCA. BOEM provided guidance for Offshore Wind development applies not just to cable routes and wind turbine locations but to additional areas that could be impacted by wind development, such as jack-up or anchor locations.

3.4 Other Stakeholder, Seabed and Ocean Users

A stakeholder is "an institution, organization, or group that has some interest in a particular sector or system", in this case the seafloor and below. There is a wide range of human activities that include, but are not limited to: fishing, aquaculture, mineral exploration, shipping, dredging, telecommunications, scientific research, homeland security, recreation, as well as renewable energy. The word "stakeholder" has is commonly used to mean a person or organization that has a legitimate interest in a project or entity. The public should be considered as stakeholders. When the public is not included as one of the stakeholders, it is not true public participation because the public would be regarded as a separate group with different rights that are not equal to the other stakeholder (groups). When the term full participation is used, both stakeholders and the public are involved. The participation of elected officials is NOT public participation. However, elected officials and their representatives (who represent the public) could be recognized as stakeholders.

It is imperative to have positive engagement with other ocean and seabed users to share information and knowledge regarding their respective industries and special interests. There is recognition that there is a need for knowledge and experience exchange in the field of coastal management, especially in areas where there is high political and public demand for the sustainable development and conservation of the coastal zone. Elected officials and their representatives (who represent the public) should be recognized as primary points of contact as a means of identifying ALL concerned stakeholders.

Of specific mention is the jurisdiction of the U.S. Army Corps of Engineers (USACE) which concerns all navigable (maintained) waterways whether inland, sheltered or in federal waters (typically 3 nautical miles offshore), noting for example that cable burial depths correspond to planned/authorized water depths and not necessarily actual or as-found bathymetry. Any obstructions to USACE activities (such as channel maintenance dredging) by installed facilities (i.e., submarine cables), will be rectified/mitigated at owners' expense, hence magnifying the importance of engaging this federal agency for planned activity in state waters.

Public Utility Commissions (PUC) which are the entities typically granting Power Purchase Agreements (PPA) may have terms included within their contracts that influence the technical aspects of an offshore facility, specifically regarding the power transmission. As such, it is recommended to ensure that any possible technical implications of the associated commercial agreements are understood as early as possible in the project development cycle.

In addition, developers should be aware that when interconnecting grid systems to other countries (i.e.,cables crossing international boundary waters) a Presidential Permit is required, as well as any other local, provincial, or federal permits required for the other countries.

3.5 Community Awareness and Acceptance

Community outreach programs are intended to provide the public with the assurance that they will be presented with comprehensive, well-communicated information; ensure concerns are heard and considered to the extent possible; and that their feedback will be reflected directly in the projects when appropriate. The target audience (aka concerned stakeholders) will have been rigorously identified as outlined in Section 3.4, above.

It is important to consider the full range of potential stakeholders who could be affected by the project to avoid the perception of exclusion or discrimination. This means looking beyond the minimum legally required distance for project notifications and outreach. As a general rule, it is strongly advisable to expand rather than limit the scope of project outreach and updates, and to consider non-geographically defined communities that might also have an interest in the project.

As an example of a best practice, all project collateral and communications should consider following 18 CFR Part 157 (APPLICATIONS FOR CERTIFICATES OF PUBLIC CONVENIENCE AND NECESSITY), FERC, BOEM, and any other regulatory body that has standards for public outreach in which the project may require. It should be noted that the public outreach requirements imposed by one agency will most likely not meet the requirements of another since the stakeholders and interested parties are not always the same.

Duplication of the standard process for public outreach will require duplication of effort but can be limited if the applicant maintains an up-to-date centralized location from which the stakeholders and interested parties can acquire current information on the project. Best practices in community and stakeholder engagement would feature the following for every project, as a minimum:

- Summary of the project goals and objectives
- Benefits of the project to stakeholders
- Activities and impacts occurring as part of the project
- Project planning and implementation timeline

Stakeholder briefings can include communicating with various community audiences, including elected officials whose districts will be impacted by the project. It is expected that such audiences would include local commercial, ecological, tourism, business development, utility, public safety and residential representatives.

As the project moves forward, stakeholder briefings should include the progress and updates on the following:

- Provide briefings to stakeholders as appropriate to the project
- Distribute regular audience notifications and updates using the most effective tactics
- Hold public meetings appropriate for scope and complexity of the project

Notifications could take a variety of forms, and to maximize outreach may include direct mailings, email updates, project alerts, partner lists, advertising, newsletters and earned media. Notification, outreach and updates should extend beyond the minimum required distance to reach those who will be affected by and/or are interested in the project. A project should include a project web page with project fact sheets and FAQs.

3.6 Grid Connection

The Federal Energy Regulatory Commission (FERC) is the United States' federal agency that regulates the transmission and wholesale sale of electricity and natural gas in interstate commerce. Independent System Operators (ISO) grew out of FERC Order Nos. 888/889 where the Commission suggested the concept of an ISO as one way for existing tight power pools to satisfy the requirement of providing non-discriminatory access to transmission. Subsequently, in FERC Order No. 2000, the Commission encouraged the voluntary formation of Regional Transmission Organizations (RTO) to administer the transmission grid on a regional basis throughout North

America (including Canada). ISOs/RTOs facilitate competition among wholesale suppliers, provide regional planning, energy and/or capacity market operation, outage coordination, transactions settlement, billing and collections, risk management, credit risk management, and other ancillary services. Across large regions, they schedule the use of transmission lines, manage the interconnection of new generation, and provide market monitoring services to ensure fair market operations for all participants.

Interconnection of the wind farm to the electrical grid is required to be able to transmit the wind farm generated power to the consumers of the power. Many of the connections to the grid will require that an interconnection agreement be established between the offshore facility and the transmission owner (TO) and/or system operator (depends on region). Because of requirements for a reliable transmission grid there are several requirements that must be satisfied and agreed to prior to the wind farm being connected to the transmission grid. Requirements vary depending on the transmission owner and the area of the country where this interconnection will take place. It is crucial that this process be started in the initial development of the project.

4 CABLE ROUTE DESIGN

4.1 Array Field Design

The array field design is between the offshore generator locations (turbines) and the OSS/OSP location. The siting for the OSS/OSP locations is addressed in section ACP OCRP 4. First the offshore generator locations are determined by energy yield assessments, seabed assessment for geotechnical conditions suitable for installation of foundations and permitting limitations. The generator layout may consider key constraints such as large sand banks or other obstacles which may be difficult for cable installation.

Current state of the art for array cables in Europe is a 72.5 kV class 3 core cable covered by IEC 63026. In the US the currently installed array cables are at 35 kV class (at the time of publication of this document). All planned US offshore wind farms will be using cables in the 72.5 kV class. Depending on the wind turbine supplier, the array cable voltage may be 66 kV or may be 69 kV. The new developments for offshore wind farms are progressing to larger size turbines and it is very likely that the array cable voltages will increase in voltage class and potentially use DC array cables.

Once the generator layout is completed, the layout of the array field cables between generator locations for collecting power can be undertaken. The standard approach is to daisy chain connection of the generators to one another into distinct "strings", which then collectively connect to the OSS/OSP, or to the onshore grid if of modest capacity and close enough to the onshore grid point of interconnection.

Common practice has been for the string to be arranged radially. This means that if an array cable is out of service, the generators upstream of it lose power supply and cannot export electrical power. In some instances, it may be appropriate or optimal to tee-in a generator to the radial string. The number of cable connections into a generator is typically limited to three, sometimes two, depending on the technology. This is because of practical considerations for cable laying, such as to reduce the risk of vessel anchor damaging a cable during installation, and to keep one side of generator free of cables for boat landing.

A looped arrangement may also be considered, where the string is connected in a ring (typically with a normally open point). Then, if an array cable is out of service, the normally open point can be closed, and all generators can be fed from the other side of the ring. The selection of this topology is subject to cost-benefit analysis of the additional CAPEX associated with the additional cable to create the loop versus the benefits of being able to continue to supply the generator auxiliary power requirements and ability to export generation during this operational scenario.

Cable sizes may be tapered so that a smaller cable size is used for sections that have less generators connected and lower ampacity requirements, and a larger cable size is used for sections that have more generators connected and higher ampacity requirements. Normally no more than two or three cable sizes are used to simplify installation logistics.

With a looped arrangement, a single larger cable size may be considered for redundancy to allow a larger proportion or all generation to be exported if a single array cable section is out of service. Alternatively, the tapered method may be applied resulting in potentially significant export limitations in an outage event. This decision will be driven by whether the primary purpose of the loop is for export redundancy or to maintain supply to the generator auxiliary system.

The layout of the array field is a cost optimization exercise, taking account of cable supply and installation CAPEX, and OPEX criteria such as electrical losses and cable unavailability. The layout should, as far as reasonably practicable to do so, minimize or avoid the following:

- Sand waves and areas of mobile sediments
- Areas where adequate protection by burial is not achievable
- Obstacles such as shipwrecks and unexploded ordnance
- Crossings of array cables, export cables or any other existing cables or pipelines
- Areas with high risk of hazards that could damage the cable

Commercial optimization software and services are available to automate this analysis, and this may be appropriate particularly for sites with many generator locations or complex site constraints.

4.2 Export Route Design

The export route is typically comprised of the following distinct sections:

- Offshore section: submarine cables between offshore substation (OSS) terminations and offshore/onshore cable transition
- Landfall Section: includes the transition from offshore to onshore
- Onshore Section: onshore cables between cable transition and project onshore substation

Additionally, there may be further cable or overhead line circuits between the generator’s onshore substation and the POI to the wider onshore grid system. This is typically referred to as the interconnection circuits and is outside the scope of this document.

US states' siting approval processes usually require that two or more routes are studied and that they are diverse in locality and technology. State siting boards usually weigh their transmission route decisions based on three key considerations:

- Reliability of Energy Supply
- Lowest Cost
- Minimum Environmental Impact

Siting approval processes require diversity of routes which are weighed with respect to these considerations. Also, different types of technologies for achieving the same, reliable energy supply goal are also required. Diversity of technology can include AC vs DC, different voltage levels, cable types, and overhead versus underground technologies.

The type of construction methods employed to install the export cable along the route is a significant factor in both Cost and Environmental Impact, two of the three major considerations by siting boards. Consequently, as part of route design, the construction methods must also be approved. Therefore, typical cable construction methods must be considered to mitigate environmental impacts to all sections of the export route including the landfall site and onshore route location. Furthermore, repair and maintenance of both onshore and offshore segments of the export cable must be considered in the route design.

4.2.1 Offshore section

The submarine transmission corridor is routed between the OSS and the landfall location. The submarine route corridor is planned and designed as a corridor as, often, decisions regarding the cable type and even the number of cables required for a project may not be known until after the corridor has been sited and even surveyed. This corridor may be based on a centerline that is designed to avoid seabed hazards, but also maximize useful data acquisition between and among hazards. In other words, the corridor centerline may not be the best possible cable route, but it should maximize the amount of useable space along the seabed and, as the corridor will form the baseline for surveys, maximize the amount of data that can be leveraged to engineer more than one route in the corridor as required.

Design factors of the submarine corridor include number of circuits, number of bundled or individual cable phases, positioning of circuits for reliability and damage protection, corridor width and circuit separation for installation and repair, bending radius limitations, cable tension limitations for laying and pulling, depth of seabed, seabed terrain and soils, burial depth, sensitive shore and marine life, configuration of laydown to accommodate bight length for repair, surface and subsurface current flow, erosion, accretion, cable movement, chafing, turbidity, noise, commercial fishing activities, shipping channels, recreational activities, proximity to other utilities and cables, unexploded devices, and installation methods.

4.2.2 Landfall section

The landfall location for the export cable route is selected based upon the following criteria:

- Proximity to and with viable and efficient onshore routes to the project onshore substation and POI.
- A location with space for all necessary civil works and laydown areas required.
- A coastline approach that is geologically stable with minimal erosion or known accretion.
- A location that has been vetted by the state and municipality (as well as stakeholders) in at least a cursory manner.
- A suitable location for transition joint, structures, and ancillary equipment to accommodate transition between offshore submarine circuits and onshore transmission circuits considering location must be accessible for maintenance, operations, and repairs.
- Suitable sand cover for burial in the nearshore area and corresponding export cable route.
- Suitable conditions for the preferred installation method (e.g., open trench or HDD).
- The presence of existing utilities and infrastructure such as other distribution cables at the landfall site.

4.2.3 Cable Transition Location

The cable transition location can be composed of any of the following: a cable vault, a cable jointing pit, a direct buried jointing pit or an anchor hang-off foundation. The cable transition location is a critical component of the export route design. The transition location and design will depend on the landfall location. It is dependent on the type of offshore submarine cable and the type of onshore transmission circuits. In most coastal areas, typically the transition will be submarine cable to underground cable. Sometimes the submarine cable is terminated directly into the project onshore substation, if it is close by the landfall location. The transition location typically contains the power cable and fiber splices as well as earthing of metallic screens and armor. Most importantly the transition location must have a foundation that can support the physical loads of the armor hang off to prevent the submarine cable being pulled back into the water. If the location utilizes a transition vault, it normally has manhole cover access to allow for future inspection and O&M activities. Design factors for the transition location consider size and length of splices, type of splices, splice supports and movement control, configuration of phases, induction between circuits, corrosion protection, link boxes, and other accessories, and ancillary equipment for monitoring.

4.2.4 Onshore Section

The upland transmission line can be overhead conductors or underground cables, or combination thereof, located between the Cable Transition Location and the Transmission Grid Substation. Recently, the trend is to place transmission underground for aesthetics especially in environmentally beautiful coastal areas.

Designing the onshore segment of the export cable considers the same factors as any underground transmission cable route design. An excellent reference is the EPRI Underground Transmission System Reference Book. Many of the topics are explained in more detail in this and other underground system references. For general guidance, some of the design considerations include topics such as route location, permitting issues, shortest available route, existing ROWs, existing roadways, congestion (urban, suburban, rural), environmentally sensitive areas, wetlands, archeological sites, environmental justice, length of segments, burial depth, paved roadway restrictions, soil characteristics, temperature, thermal resistivity, major infrastructure crossings (railroad, highways, etc.), seasonal obstacles/traffic control, survey and data collection, heat sources, EMF, vault placement, bending radius, pull lengths, delivery length limitations, pulling tensions, pull site equipment set up, maintenance and access for repair, interference, and proximity to other vital utilities.

4.2.5 Onshore Substation

The project's onshore substation is preferred to be near the POI which is typically an existing site owned by the region's utility or Transmission System Operator. In each US state, siting guidance for a new substation or its expansion is the same. For guidance for substation siting and design reference 1127 IEEE Guide for Design, Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility.

4.3 Crossings / Proximity

4.3.1 Cable / Pipeline Crossings

Installation procedures and protection requirements for cable and pipeline crossings should be agreed upon by the third-party owners of those existing (or impending) infrastructure as part of the installation pre-engineering work.

Recommendations for cable and pipeline crossings can be found in the following documents:

- ISO 13628-5, Petroleum and natural gas industries - Design and operation of subsea production systems—Part 5: Subsea umbilical's, Section 15.15: Pipeline crossing

- ICPC Recommendation No. 3, Telecommunications Cable and Oil Pipeline/Power Cables Crossing Criteria, to be applied to proposed crossings between submarine telecommunications cables and pipeline/power cables

4.3.2 Proximity Issues

Submarine cables will most likely have to cross existing other buried submarine utilities which places the two utilities in close proximity. Additionally, offshore structures will also be in close proximity of offshore wind farm cables and structures. For addressing proximity issues between submarine cables, structures and utilities, it is recommended to consult ICPC Recommendation 13, The Proximity of Offshore Renewable Wind Energy Installations and Submarine Cable Infrastructure in National Waters. This document provides information on issues regarding construction and intervention/repair imposed by adjacent facilities in operation and the associated hazards. Submarine cables have been suffering faults since the first installation over 160 years ago and unfortunately cable faults will still occur in the future. The need to restore a system quickly has always been paramount and has been recognized in several treaties, most recently in the United Nations Law of the Sea Convention (1982) ("UNCLOS"). Stakeholders during the development of crossing agreements and discussion on proximity limits between submarine cables and offshore wind farm structures are advised to develop and agree safe and appropriate solutions on a case-by-case basis to determine how much sea room is actually needed to efficiently and safely execute a cable repair. The experience acquired in repairing submarine cables has evolved into a recognized set of maintenance and repair processes and procedures. To assist all sectors in understanding the interactions and impacts, four key determinants of sea room required by a cable ship are:

- Fault location
- Cable recovery
- Cable repair
- Re-deployment

(Ref: ICPC Recommendation No.13, Issue: 2B Issue Date: 26 November 2013, or latest revision)
When planning the route of submarine cables, it is recommended that developers consult the following documents:
From ICPC:

- Recommendation No.1: Recovery of Out of Service Cables
- Recommendation No.2: Cable Routing and Reporting Criteria
- Recommendation No.3: Telecommunications Cable and Oil Pipeline / Power Cables Crossing Criteria

- Recommendation No.4: Co-ordination Procedures for Repair Operations Near In Service Cable Systems
- Recommendation No.7: Offshore Civil Engineering Work in the Vicinity of Active Submarine Cable Systems

4.4 Cable Burial and Protection Considerations

Decisions on cable burial depth and/or other means of protection in nearshore and estuarine areas may be influenced by the need to address the impacts of an increase in presence of other seabed users (e.g.,recreational and commercial fishers) and the added risks associated with higher levels of vessel traffic in areas of the cable route. In event that such risks are identified and credible, it is recommended that protection measures be considered to reduce, to as low as reasonably practicable, any risks to the cable or other seabed users. Such measures may include, but not be necessarily limited to: Increased burial depths, matting or possibly charted NO anchor zones, for example. There is no standing rule, or "one-size-fits-all" solution, hence it is recommended that each circumstance be evaluated on a case-by-case basis. The following paragraphs give further guidance on how to undertake the burial risk assessment.

In reality, cable burial depth analysis is a technical optimization between determining the cable's minimum burial depth specification to afford mechanical protection from recognized risks while minimizing the depth of cover to allow for better cable ampacity, or power flow.

4.4.1 Cable Burial Risk Assessment

Burial as a method of protection for a subsea cable can provide mitigation against the potential hazards for array and export cables. The optimum burial should be determined by applying a risk-based approach, which may result in varying burial depths along the routes or across the site. Methodology for the risk based burial approach is given within DNVGL, and also CT documents referenced below.

- Carbon Trust, 2015, Cable Burial Risk Assessment Methodology, Guidance for the Preparation of Cable Burial Depth of Lowering, CTC835
- Carbon Trust, 2015, Application Guide for the Specification of the Depth of Lowering using the CBRA Methodology
- DNVGL, 2016, Subsea Power Cables in Shallow Water, DNVGL-RP-0360
- DNVGL, 2016, Subsea Power Cables for Wind Power Plants, DNVGL-ST-0359

Typically, the primary hazards to be mitigated by burial include:

- Anchor Strike – Depth to ensure an acceptable annual frequency of interaction from anchor drag (i.e.,from an anchorage) or emergency anchoring interaction
- Fishing Gear Strike – Maximum Penetration of Fishing Gear Types along sections of the cable route(s)
- Exposure due to mobile seabed

The output of the CBRA is several threat lines for each of the hazards where cable burial is identified as a mitigation measure. Often the threat lines are dependent on the interpreted ground conditions. The CT documents indicate that it is typical not to protect against all vessel types in the area. Instead protect against vessels of a threshold size to achieve an agreed level of acceptable risk. The recommended practice DNVGL-RP-0360 advises applying a risk-based approach for determining the optimum burial depth. There is no specific risk assessment defined in DNVGL-RP-0360; however, it recommends that "some guidance may be derived from the submarine pipeline sector, see e.g., DNVGL-RP-F107".

Application of DNVGL-RP-F107 to offshore wind is considered a good starting point. Nevertheless, the risk framework proposed in DNGVL-RP-F107 has been developed for pipelines for the Oil & Gas business and as such, it is considered conservative, in some respects, when benchmarked against the offshore wind industry. Therefore, the risk assessment framework proposed in DNVGL-RP-F107 is recommended to be adapted to be used for offshore wind projects. One example being the environmental impact of striking a pipeline with an anchor has a considerably higher consequence to a similar strike of an offshore power cable.

4.4.1.1 Ground Condition Assessment

In order to provide input into the Seabed Mobility and CBRA the desktop study information, site specific geophysical data and geotechnical data is interpreted along the cable route(s) and zoned into areas of similar ground conditions. All aspects regarding the ground conditions assessment are considered within ACP OCRP-4.

4.4.1.2 Seabed Mobility

A seabed mobility assessment is recommended to predict changes in the seabed morphology within the site. Understanding the seabed morphology is key to help define, amongst other requirements, the burial depths for the cable route.

For use within the thermal parameters assessment the maximum seabed level may also be required. In areas where significant seabed mobility exists, lifetime protection may not always be possible at the time of installation and therefore an in-life protection strategy could be considered which aims to mitigate risk throughout the lifetime of the asset.

Seabed mobility is discussed further within ACP OCRP4.

4.4.2 Target Burial Depth

For the designed cable route, a burial assessment study is required. The burial assessment will need to detail the following:

- risks along the cable route
- suitable (lay and) burial method(s) and resulting trench profiles based upon the sediment conditions
- additional protection that may be required

Details regarding this are given within DNVGL, 2016, Subsea Power Cables in Shallow Water, DNVGL-RP-0360.

The target burial depth represents the depth that the Offshore Cable Installation Contractors should aim for during the primary burial campaign. The target burial depth needs to be established using the information acquired during the CBRA, predicted seabed level at time of installation, and third-party requirements.

The burial depth will generally be the greater of the depth determined from the CBRA plus sediment mobility and any third-party requirements. On certain occasions if the burial depth exceeds the depths that can be achieved in practice using the available tools on the market, or if it limits the thermal rating of the cable then a lifetime protection strategy may not be achievable in practice and an in-life protection strategy will need to be developed.

4.4.3 Remedial Assessment and Lifetime

During Installation unforeseen factors such as mechanical breakdown, unforeseen ground conditions or operational constraints may result in sections of cable not achieving the burial depth despite best efforts by the installation Contractor.

Typically, during construction two types of remedial options are available, subject to the feasibility, practicality, relevant permits, and site conditions:

- Re-burial, for example, via jet trencher or Control Flow Excavator (CFE).
- Secondary protection such as with concrete mattresses, rock protection, rock bags or external mechanical pipe, etc.

4.5 Planning for Inspection & Maintenance, Repair

As part of overall Operations and Maintenance plans, Developers must consider the repair and maintenance of proximate and crossed cables, and in particular the risks associated with the fault location, recovery, repair and deployment of the repair bight on the seabed as well as initial excavation and post repair protection, by burial or otherwise.

With bundled cable configurations there will be a requirement to repair all cables in the bundle, with the assumption that the repaired bundle will be laid out on the same side of the cable route. In some instances, it may be acceptable to deploy the repair bight over an adjacent cable, but the commercial and technical risks associated with such a strategy would have to be fully assessed. The final bight length (displacement from the original cable line) of a cable repair, or indeed, final installed joint in a cable system is a function of water depth, the physical characteristics of the cable, constraints of the repair vessel layout and prevailing weather conditions at the time of laydown operation. Therefore, when considering initial cable spacing of export cables in relatively close proximity, the design separation should consider maintenance strategy allowing for potential repairs to the cable(s) including recovery (whether by ROV or by de-trenching grapnel) and redeployment – while also bearing in mind proximity to turbines, OSPs and any third-party cables or pipelines. Particular regard should be given to repair strategy and planning at the earliest stages of project design, where multiple cables might fan from shore landings and OSPs. It is, therefore, not possible to specify a cable separation in this context; a case-by-case assessment must be made. This spacing becomes more critical as number of adjacent circuits, or cables, increase.

Further guidance is given in “Offshore Wind Submarine Cable Spacing Guidance”, Contract # E14PC00005, US DOI – BSEE, December 2014, and references therein.

5 SITE INVESTIGATIONS AND DATA HANDLING

5.1 Importance of Survey

Surveys are critical to informing and optimizing planning decisions, the cable route, the cable design, the installation methodology and tools, the capabilities of the installation vessel and the time required for operations, landfall installation methodology, amongst other things. The information helps to reduce uncertainty and risks to a manageable level.

Cable designers require survey information such as thermal resistivity, Ground Model and sediment mobility to enable effective cable design. Installation and burial contractors need survey information to select appropriate cable installation and protection methods. Surveys provide a basis for optimizing cable protection using a risk-based approach. The cable protection solution(s) need to be determined during the planning stage, taking into consideration the risk of cable damage and therefore outage of the cable transmission system. The cost benefit in terms of project de-risking, must be determined for the optimum timing for execution of site surveys where a philosophy of "the earlier, the better" may apply.

5.2 Site Investigations

Geophysical remote sensing and intrusive geotechnical data collection methods are used to identify and analyze cable hazards and risks. Engineering and site characterization surveys typically comprise of various types of investigations, including geological and geophysical surveys along with geotechnical investigations. Methods and investigative tools should be customized to meet project design needs and local conditions. Site investigation data used to inform the engineering and design are often used for other applications such as the federal and state information requirements (the identification of cultural resources and benthic habitat classifications), so care must be taken to ensure the needs of all data users are considered prior to data collection efforts.

While there are a variety of ways to approach an offshore wind site investigation, it is typically an iterative process where each subsequent operation or investigation provides additional key information often with increasing spatial resolution and analytical complexity. The process generally starts with a desktop study where all existing public information about site conditions, hazards, and man-made constraints is collected and analyzed for initial design of the project and cable routing options. As the project moves forward, data collection operations take place to collect site specific information on water depth, seabed conditions, soil thermal resistivity at burial depth and subsurface geology/stratigraphy to further refine project design and cable routings. A qualified and experienced geophysicist and geotechnical engineer with knowledge of the site should lead the scoping and execution of the site surveys and investigations, including the preparation of laboratory testing schedules. Details regarding both the geophysical and geotechnical investigations are given within ACP OCRP 4.

5.2.1 Federal Information Requirements

The developer should submit the results of its site characterization surveys (with supporting data) to BOEM as described in 30 CFR part 585. Using data from the geologic, geophysical, and geotechnical site characterization surveys, the developer should compile a marine site investigation report focusing on factors such as geologic hazards, man-made risks, soil thermal resistivity at burial depth, and others that may constrain and influence cable design, project engineering, or affect system integrity. The marine site investigation report should contain proposed cable routings or a plan to develop the routings complete with project schedule including key milestone dates. The routings, methods, and design can be further refined though the permitting process however the initial submission must include the full range of activities to be considered such that new methods or project parameters are not proposed later in the process.

Guidance for conducting a route survey can be found in the following documents which covers the requirements for any site:

- - Guidelines for Providing Archaeological and Historic Property Information Pursuant to 30 CFR 585
- - Guidelines for Providing Geophysical, Geotechnical and Geohazard Information Pursuant to 30 CFR 585
- See reference: www.boem.gov/newsroom/notes-stakeholders/updated-geophysical-geotechnical-geohazard-and-archaeological

5.2.2 Desktop Studies

The objective of a desktop study is to identify the hard constraints of the project, in this case the cable design and routing, to avoid major delays or redesign efforts later in the process and provide information and project feasibility analysis. The study will generally compile publicly available information on the areas under consideration for cable risks such as shipping lanes, anchorage areas, marine protected areas, military warning areas, seabed conditions, fishing activities, and existing and future submarine cable and pipeline projects among others. Guidance for the requirements of a desktop study can be found in the following document:

- ACP U.S. Recommended Practices for Geotechnical and Geophysical Investigations and Design OCRP-4
- ICPC Recommendation, Recommendation No.9, Minimum Technical Requirements for a Desktop Study (also known as a Cable Route Study)

5.2.3 Project Design Investigations

Project design investigations include the collection of information and data to design and engineer the cable and routings, generate the marine site investigation report, the cable burial risk assessment, cultural resource assessment, benthic habitat classification, and assessment of risk associated with MEC. As described above, the investigations are typically a series of marine data collection operations that increasingly refine the understanding of site conditions. The nature and purpose of these investigations should be site specific and target project and permitting needs.

References for additional information:

- BOEM Survey Guidelines ACP U.S. Recommended Practices for Geotechnical and Geophysical Investigations and Design BOEM Survey Guidelines can be found here: https://www.boem.gov/renewable-energy/survey-guidelines-renewable-energy-development
- Geotechnical & Geophysical Investigations for Offshore and Nearshore Developments, ISSMGE, September 2005.
- ICPC Recommendations 1 through 14 (http://www.iscpc.org/).
- IHO Standards for Hydrographic Surveys, Special Publication N° 44, 2008.
- Marine Soil Investigations, NORSOK Standard G-001, October 2004
- Standard DNVGL-ST-0359, Subsea Power Cables for Wind Power Plants, DNV GL, June 2016.
- Recommended Practice DNVGL-RP-0360, Subsea Power Cables in Shallow Water, DNV, 2016.
- Cable Burial Risk Assessment Methodology, Guidance for the Preparation of Cable Burial *Depth of Lowering* Specification, Carbon Trust, CTC835, February 2015
- OSIG, Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments, May 2014

5.3 Management of Route Data

Cable route survey data should be well managed and organized with appropriate metadata to identify data sources, acquisition parameters, and processing procedures. Data should be managed via database or series of folders and digital library. It is important to think long term during the early stages of data collection and development of the management protocol to ensure the resulting data can be integrated over the project’s lifecycle.

See ACP OCRP 4 for additional information.

6 CABLE DESIGN

Array cables interconnect WTGs and bring power from wind turbines to a collector point. Export cables move power from a collector point to the onshore substation which is sometimes the same location as the POI. Standard voltage levels can be found in either ANSI C84.1 or IEC 60038.

6.1 Export Cables

Power Export Cables and Export Cable terms are used interchangeably.

6.1.1 General

With larger windfarms, the power generated by the WTGs offshore is collected at an OSS/OSP. The power is then transferred to the shore by means of submarine export cables.

There are two types of export cables: HVAC export cables and HVDC export cables.

The first type has been most commonly used in the offshore wind industry so far. In general, HVAC export cables are used to connect the OSS/OSP to the onshore substation. Typically, each AC circuit consists of a three-core submarine cable for the offshore section jointed to three single-core land cables at a transition joint just inland of the landfall point. Today, three-core submarine HVAC export cables are starting to become available for voltages up to 420 kV. It is uncommon but also feasible and possible to use submarine single-core HVAC cables for the offshore section, allowing the increase of power transfer capabilities of the cables, but increasing the number of cables to install. Single-core cables that are solidly bonded have metallic shield dc resistance equal to the conductor dc resistance to accommodate the return currents in the metallic shield.

HVDC export cables are an alternative technology and have larger power transfer capacities than HVAC export cables; however, the requirements for converter station offshore and onshore makes HVDC systems often more expensive than HVAC solutions depending on the transmission distance and capacity required. Today in the offshore wind industry, HVDC systems are used as offshore power hubs which collect the power produced by several offshore wind farms.

For more information regarding different cable types, reference is made to CIGRE TB610.

There is no international standard specifically setting the rules for design of submarine cable with voltages above U_m=72.5 kV for HVAC cable and for any voltages for HVDC cable. CIGRE TB 490 and CIGRE TB 610 provide some information and guidance; however, the component cable design consisting of jacketed cable cores chosen by the cable manufacturer should fulfill testing requirements to an accepted international standard. The assembly of the cable system should be tested to follow CIGRE TB and IEC standards for submarine cable assemblies. The fulfillment of these requirements and recommendations can guide the design choices to be made.

6.1.2 Conductor

Conductors are made of copper or aluminum and different configurations can be used depending on the use of the cable.

- Stranded conductors made of several round wires is the most common type for HVAC cables but can also be used for HVDC cables. Stranded conductor can be compressed or compacted using dies.
- Profiled conductors are made of keystone shaped wires that are stranded together to form a conductor with reduced spaces between the wires. This type of conductor is the most commonly used for HVDC cables, although it is also widely used for larger cross section HVAC cables.
- Solid conductor consisting of one single wire are also used

For information concerning cable design, reference is made to CIGRE TB 610, section 5.2. IEC 60228 covers solid, stranded, and segmental conductors.

In case of damage to cables, measures such as water blocking compound, WBP or WBT should be taken for the submarine cables to reduce the longitudinal water penetration in the conductor. If a limited length of conductor is exposed to water a reduced spare cable length would be required. This should apply to wet designs and dry designs equally.

For testing the longitudinal and radial water penetration, reference is made to CIGRE TB 623, section 5.4, or IEC 63026 for cables with voltage up to 72.5 kV (reference is made for the method of testing). Note: these requirements may vary from the component cable core with jacket requirements. Note that CIGRE TB 490, section 8.7 is referenced in the above documents.

6.1.3 Insulation system

For any type of export cables (i.e., HVAC and HVDC), the insulation system consists of three separate elements:

- Inner or conductor semiconducting shield*
- Insulation layer
- Outer or insulation semiconducting shield*

**Note: In countries outside of North America it is common to refer to these layers as screen instead of shield. See Section 2.4.2 of this document.*

The inner and outer semiconducting screen are applied to smooth the electrical field at the conductor (inner semi-conductive) and insulation (outer semi-conductive) interface, and thus avoid concentration of electrical field and local stresses. Semiconducting screens are made of insulating material in which conductive material has been added.

The insulation layer is composed of insulating material with a certain dielectric strength that provides a barrier between surfaces with different potential. Different material can be used depending on the cable use.

The insulation semiconducting screen serves several functions including, to obtain symmetrical radial stress distribution with the insulation, exclude other materials from the dielectric field, and to protect from induced or direct over-voltages.

6.1.3.1 HVAC Application

Today, the vast majority of HVAC export cables have an extruded insulation system. For voltages up to 420 kV, the material used for the insulation layer is cross-linked polyethylene (XLPE). The semiconducting screens are also made of XLPE to which carbon black is added to give the conducting characteristic of the screens. Additional polymers (e.g., EPR, polypropylene, etc.) are being used in cable applications.

The three layers of the insulation systems are extruded simultaneously in a triple extrusion process which ensure a smooth and firmly bonded interface between the insulation layer and the semiconducting screens. Immediately after the extrusion, the cross-linking process is performed in a sealed tube at high pressure and temperature, giving thermal stability characteristics to the XLPE. Cross-linking is an irreversible process and re-melting is not possible.

For voltage up to 150 kV, other materials such as Ethylene-propylene rubber (EPR) may be used.

The insulation system thickness and material compatibilities are chosen by the cable manufacturer based on experience, design life calculations, or standards-based requirements and are validated by type tests and prequalification tests where applicable.

Details on the insulation system design for HVAC export cables can be found in section 3.3 of CIGRE TB 490 and section 5.3 of CIGRE TB 610.

6.1.3.2 HVDC Application

For HVDC application, two different technologies are available for the insulation system, Mass Impregnated (MI) insulation or extruded insulation.

MI cables are available and in use for voltage up to ± 600 kV. The insulation layer is composed of lapped paper tapes and the semiconducting screens are made of lapped carbon black coated paper tapes. The insulation system is impregnated with high viscosity fluid which provides additional insulation properties. The thickness of insulation system is defined by the cable manufacturer to reflect the electrical stresses during the cable lifetime and is based on experience and is validated by type tests and prequalification tests.

Mass impregnated insulation systems have been used for more than 70 years for HVDC power cables.

The design of the insulation system for a HVDC submarine cable with extruded insulation is similar to the design of the insulation system of HVAC submarine cable. The insulation system is made of three layers of XLPE material, the inner and outer screen being semiconducting with the addition of carbon black whereas the insulation layer is electrically insulating. Even if the material is of the same type between AC and DC, the compounds used are different and DC cables have specific compounds developed for DC applications due to thermally induced voltage-stress inversion.

Similar to the MI insulation thickness, insulation system thickness for the extruded insulation is defined by the cable manufacturer based on experience and validated by type tests and prequalification tests.

XLPE extruded insulation for DC applications have been used since the beginning of the 2000s. As of the generation of this document, all the HVDC submarine with extruded insulation installed have a voltage level of ± 320 kV or lower with the exception of one HVDC submarine cable with a voltage level of ± 400 kV between UK and Belgium. However, HVDC submarine cables with voltage level up to ± 525 kV with XLPE insulation have been qualified but none are currently installed and in service.

6.1.4 Metallic layer

Detailed information about metallic layers can be found in section 3.4 of CIGRE TB 490 and section 5.4 of CIGRE TB610.

6.1.4.1 HVAC Application

In general, one or more metallic layers are used in HVAC submarine export power cables. These layers serve at least one of the purposes listed below:

- Carry the fault currents in the event of an earth fault (fault currents provided by system study)
- Be a path for capacitive leakage current
- Keep the insulation dry
- Minimize to almost zero the electric field outside of the metallic layer

The majority of HVAC submarine export cables with voltage over U_m>72.5 kV have an extruded lead sheath as metallic layer. The advantage of the lead sheath is that it serves all the purposes listed above, has great water blocking capabilities, and its proven long-term reliability. Research and development is underway to find cost-effective alternatives for lead in Europe which will migrate to the United States as it is developed and commercialized.

Water swellable tapes are also applied under the lead sheath as longitudinal water barrier to avoid, in the event of a damage of the lead sheath, diffusion of water along (longitudinally) the cable.

However, depending on the cable design, operating voltage and application, other solutions may be available. A lead sheath cannot be used in a dynamic cable because of lead's low resistance to fatigue.

6.1.4.2 HVDC application

For DC application, the metallic layer is used for the following:

- Equalize the electric field
- Keep the insulation dry
- Return fault currents

For HVDC cables with MI insulation, water tightness of the insulation is mandatory to keep the insulation dry and keep the fluid within the insulation system, thus a lead sheath is extruded over the insulation system. Furthermore, MI insulation systems are subject to expansion when the temperature increases, which can cause deformation and/or damage of the lead sheath and can result in the loss of water tightness. Additionally, MI cable can have an issue when the temperature decreases it can create voids between the paper insulation that can lead to dielectric breakdown. To avoid this, metallic reinforcement tapes are applied over the insulation system and under the lead sheath.

Water swellable tapes are also applied under the lead sheath as longitudinal water barrier to avoid diffusion of water along the cable in the event of damage to the lead sheath.

For HVDC cables with XLPE insulation, lead sheaths are often also used as metallic layer and radial water barrier. Since thermal expansion is limited with polymeric insulation, reinforcement tapes can be omitted.

6.1.5 Core over sheathing

When lead sheath is applied, it is recommended to apply a polymeric sheath, typically polyethylene, over the metallic layer for protection against mechanical damage. Extra attention should be taken to limit the transient over voltages if jacket is insulating. Semi-conducting PE compound, where carbon black is added, can be used to avoid over voltages (transients are not a concern).

6.1.6 Lay-up

HVAC submarine cable systems are usually supplied as three-core cables to reduce the installation scope and improve the cable ampacity due to reduced losses in the metallic shield.

The three sheathed power cores are laid up using a planetary type laying up machine, which avoids the imposition of torsion stresses on the sheathed cores. Fiber optic elements can be inserted in the interstices during this process. Extruded polyethylene fillers or polypropylene yarns are applied in the interstices to give a substantially round shape. In general, profiled extruded polyethylene fillers provide a rounder shape to the bundle. The assembled cores are bound together with synthetic tapes. Refer to Section   for joint requirements.

6.1.7 Armor

Armoring is specific to submarine power cables. During installation, submarine power cables are subjected to mechanical forces (i.e., tensional, and torsional forces), potentially very important depending on the installation depth. Thus, to withstand these forces, armoring is applied as a strength element of the cable.

In addition, the armor is also essential for protecting the submarine cables against external hazards during the cable lifetime, such as:

- Anchor dropping
- Fishing activities e.g., trawling
- Dumping of rocks or other materials
- Dredging
- Others submarine installations

The level of damage caused by these hazards is highly dependent on the installation depth, seabed characteristics, burial depth as well as protection strategy chosen.

In any case, the armor of the cable should be properly designed to reduce the risks of damage.

Armor is mainly designed with one or two armoring wire layers depending on the project and installation requirements. Along one cable length, it is also possible to add or remove a layer of armoring. As an example, where extra pulling forces are necessary and/or extra tensional strength is required, double armoring may be applied.

Galvanized steel wires are the most widely used armor material. However, depending on the specific project, stainless steel, other materials (e.g., polyethylene, aluminum, Kevlar, etc.), or a combination of materials can also be used as well.

In DC applications, no armor losses are created because of the nature of DC current. There is no induced current in the armoring. Thus, magnetic steel armoring is the most common solution for DC application.

Corrosion protection is also important for the armoring because of the nature of the material used for the armor. The most common corrosion protection for steel wires is hot dip galvanization. In addition, armoring layers are usually flushed with hot bitumen to add an extra protection. Other methods are identified in the standards below.

Refer to CIGRE TB 490 section 3.5 and CIGRE TB 610 section 5.5 for guidance on armoring design and further details on mechanical forces, armor losses, and corrosion protection. Refer to CIGRE TB 623 for the mechanical testing of the armoring.

6.1.8 Outer serving

The outer serving usually consists of asphaltic compound with polypropylene yarn reinforcement. A few yarns have a different color to visualize the cable on the seabed during installation. Furthermore, different cables may have the few yarns in different colors or different number of colored yarns to distinguish the different cables or circuits after commissioning.

The outer serving can also be a polyethylene sheath.

With both choices, water will penetrate in the cable up to the metallic shield.

6.1.9 Cable Ampacity Calculations

As a baseline, cable ampacity calculations (dimensioning) should be performed following the calculation methods specified in IEC 60287, IEC 60853, and IEC 62095 (for finite element method calculations). However, much research has over the recent years shown that the IEC 60287 and 60853 are conservative especially for three phased submarine cables with armor. Therefore, adaptions of the IEC 60287 and 60853 as well as alternative calculation methods are now standard to use in the industry. This includes but is not limited to Finite Element Analysis (FEA), more accurate estimation of armor losses, cables in J-tubes, deeply installed cables in land fall HDDs, etc. A combination of these and similar methods can be used to optimize the cable ampacity calculations. Note, a draft CIGRE technical brochure (CIGRE WG B1.56) is to be published in the near future with examples of how to calculate three-core submarine cable ampacities and other specific instances not covered by IEC standards. It is important to note that cables for wind farms do not need to be able to carry the maximum steady-state power, and thus reference is made to section 5.9 and Appendix D.5 of CIGRE TB 610, as well as CIGRE Session 2016 B1 303 paper, where examples of how a predicted worst-case loading profile based on measured or assumed wind data of the cable can be obtained. This is referred to as "dynamic loading" for wind farm cables. A CIGRE working group (CIGRE WG B1.67) is working to generate a technical brochure related to dynamic loading ampacity calculations.

Note: No existing standards currently define the calculation method for electro-magnetic fields of three-core submarine cables. Be aware this issue may be raised by permitting agencies.

6.2 Inter-Array Cable Design

The terms IAC and Array cable are used interchangeably among the standards.

6.2.1 General

Inter-Array cables are cables used to connect individual wind turbines to each other and to collect the power produced by several wind turbines to the offshore substation.

IACs are typically three core AC cables. The voltage level used is dictated by the voltage level of the WTGs. Historically, the voltage level used was $U_m = 36$ kV. However, with the increase of the size of WTGs in the last years, the voltage level has increased to U_m=72.5 kV.

From a standard point of view, submarine IAC design, testing methods and requirements are covered by IEC 63026 for cables with extruded insulation and rated voltages from 6 kV (U_m= 7.2 kV) up to 60 kV (U_m= 72.5 kV).[3]

6.2.2 Conductor

Conductors can be made of stranded or solid conductor, in copper or aluminum. Stranded conductor can be made of round or shaped wires. Solid conductor consisting of one single wire can also be used.

In case of damage to the cables, measures such as water blocking compound, WBP or WBT should be taken to reduce the longitudinal water penetration in the conductor, so a limited length of conductor is exposed to water, hence a reduced spare cable length would be required.

Conductor design should follow the requirements of IEC 60228, according to section 5.1 of IEC 63026.

If cores are being designed to an ICEA standard the conductor design should follow that standard, unless specifically requested otherwise.

For testing the longitudinal water penetration, please refer to TB 490, section 8.7, CIGRE TB 623, section 5.4 or IEC 63026 section 12.6.2.

6.2.3 Insulation System

Similar to export cables, the insulation system of IACs should consist of three separate elements:

---

[3]There are no North American standards with full applicability to array cable design. However, a central component in these cables are the cable core insulation systems. These insulation systems are well specified by longstanding ICEA standards,

ICEA S-108-720 Standard for Extruded Insulation Power Cables Rated above 46 through 500 kV AC

ICEA S-94-649 Standard for Concentric Neutral Cables Rated 5 Through 46 kV

ICEA S-97-682 Standard for Utility Shielded Power Cables Rated 5 Through 46 kV

- Inner or conductor shield*
- Insulation layer
- Outer or insulation semiconducting shield*

**Note: In countries outside of North America it is common to refer to these layers as screen instead of shield.*

The IAC insulation layer should be made of extruded dielectric material. The material should be XLPE or EPR.

The inner and outer screen should be made of semi-conducting compound that is extruded and firmly bonded to the insulation layer.[4]

Detailed information for the design of insulation system can be found in sections 5.2 and 5.3 of IEC 63026.[5] A key difference between the ICEA standards listed above and IEC 63026 is in the treatment of insulation systems. The ICEA standards define multiple classes of insulation as well as non-conductive conductor shields specific to one class of EPR and recognize the different test requirements and limits required of these materials. For cable core designs using EPR insulation systems, either the above ICEA specifications or IEC 63026 standards may be followed for core qualification and routine tests. Specific areas in which ICEA standards may be applied to specific EPR core insulation system designs are footnoted throughout this document.

6.2.4 Metallic Layer

Because of limited electric stress, the need of metallic water barrier is not required for IACs. Thus, two main designs can be found:

- Wet design: no metallic water barrier is applied, or a metallic screen is applied but insulation system will be in contact with water over time.

---

[4] For cable cores with Class I DR-EPR insulation as defined in standards ICEA-S-108-720 and Class III DR-EPR insulation as defined in ICEA-S-93-639, a non-conductive conductor shield (screen) extruded and bonded to the overlaying insulation may be employed, additionally the semi-conductive insulation shield may be bonded or non-bonded to the insulation.

[5] For cable cores with EPR insulation, detailed information for the design of the insulation system can be found in standards ICEA-S-108-720 and ICEA-S-93-639, ICEA S-97-682, and ICEA S-94-649.

- Dry design: a metallic sheath is applied

Refer to section 5.4 of IEC 63026 and CIGRE TB 722 for more information on metallic screen.

CIGRE TB 722 defines the requirements that must be met to classify the cable design as dry. Otherwise, the cable design should be considered wet.

Note: Semi-wet design is a term that has appeared in prior literature and should be considered wet design unless it can pass the test regime per CIGRE TB 722

6.2.4.1 Wet Design

In this case, no water barrier is applied, and the insulation system is in direct contact with water. Manufacturer should perform long-term accelerated wet test according to CIGRE TB 722, to prove the performance of the insulation system under wet conditions over time.[6] Note that ICEA accelerated water tree tests are similar to the IEC/CIGRE accelerated aging of dielectric test. Water/Saltwater used in tests should contain a salinity relevant for the application, reference CIGRE TB 490.

With some wet designs, potential short circuit currents are not carried by the metallic screen. For cables with such design, the short circuit currents would be carried by the armor. Other wet designs may employ a metallic screen or neutral wires that carry the short-circuit currents. Alternative designs may be possible.

6.2.4.2 Dry Design

In some situations, it is required to have a dry insulation system for the IACs. In these situations, a metal sheath is required as the water barrier to block all water including water vapor. CIGRE TB 722 defines the requirements that must be met to classify the cable design as dry. Otherwise, the cable design should be considered wet.

---

[6] For cable cores with EPR insulation, the accelerated water tree tests to prove the performance of the insulation system under wet conditions may be as required in ICEA-S-108-720 and ICEA-S-93-639, Appendix K, ICEA S-97-682, and ICEA S-94-649 with the modification that water salinity outside the cable should have salinity relevant for the application. Water through the conductor core should remain tap water.

6.2.5 Jacket

When required, a sheath of polymeric polyethylene is applied over the metallic layer for protection against mechanical damage. Extra attention should be taken to limit the transient over voltages. Semi-conducting PE compound, where carbon black is added, can be used to avoid over voltages. For details refer to the following standards:

- CIGRE TB 797 Sheath Bonding Systems of AC Transmission Cables - Design, Testing, and Maintenance
- IEEE 575 Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV.

6.2.6 Lay-up

IACs are typically supplied as 3-core cables to reduce the installation scope and improve the cable ampacity due to reduced losses in the metallic shield. The three sheathed power cores are laid up using a planetary or S-Z type laying up machine, which avoids the imposition of torsion stresses on the sheathed cores. FO elements can be inserted in the interstices during this process. Extruded PE fillers, EPDM fillers or PP yarns are applied in the interstices to give a substantially round shape. In general, profiled extruded PE fillers provide a rounder shape to the bundle. The assembled cores are bound together with synthetic tapes.

6.2.7 Armor

The design considerations to be taken for IACs are the same as for export cables. Refer to section 6.1.7 above as well as section 5.7 of IEC 63026 for more details on armoring.

6.2.8 Outer Serving

The outer serving usually consists of asphaltic compound with polypropylene yarn reinforcement. A few yarns could have a different color to visualize the cable on the seabed during installation. The outer serving can also be a polyethylene sheath. With both choices, water will penetrate in the cable up to the metallic shield.

6.2.9 Cable Ampacity Calculations

Refer to Section 6.1.9 of this document.

6.3 Dynamic Cables

Dynamic cables are cables exposed to environmental conditions differing from buried cables during their operational lifetime. For example, a cable that is connected from the seafloor to a floating structure, or another example would be a cable suspended from a fixed structure passing through the water column exposed to water current and waves. Dynamic cable technology is new, and the only existing references are CIGRE TB610 Section 9, CIGRE TB 623 section 3.7 and CIGRE TB722 section 3.10. Dynamic cables can be applied to both export and IACs described in Sections 6.1 and 6.2 of this document.

6.4 Optical Fibers

Optical fibers are mainly used for the communication and control of the offshore wind farms and WTGs. Control of the substation/converter and the WTGs, via the SCADA system, can then be performed remotely from shore. In addition, optical fibers can be used to monitor the cable systems and assess the cable temperature or strain, amongst other properties.

For three-core export or IACs, fiber optic cables can be easily integrated in the interstices between the power phases during the manufacturing. In this case, they are often referred as optical fiber elements. For single core export cables (for instance for HVDC), an armored optical fiber cable can be supplied and installed either separately or in bundle with single core cables. Alternatively, the optical fibers can be inserted within a sheath or integrated in the cable armor. The fiber optic cable should be designed such that if a break occurs in the metallic tube of the fiber optic cable no voltage gradients will occur due to induced voltages.

Current offshore wind farms are developed up to 200 km from the shore, so an unrepeated system (fiber optic cables with no electrical reamplification) should be suitable for this distance range. When fiber optic cables are longer than 300-400 km, repeaters should be considered depending upon the optical power budget required. Only unrepeated optical fiber systems will be addressed in this section.

Additional information about optical fibers can be found in CIGRE TB 610, section 5.7.

Historically, the design life of optical fibers is less than the industry accepted design life of the overall power cable due to aging factors such as hydrogen embrittlement. This needs to be considered in the overall design life of the cable system within which it is employed.

Note: There is a CIGRE working group (CIGRE WG B1.70 Recommendations for the use and the testing of optical fibers in submarine cable systems) that should be consulted when the TB is released.

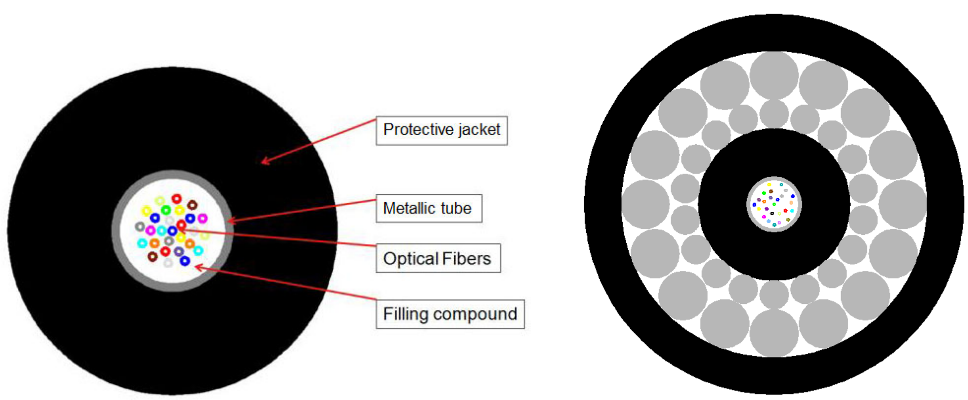
6.4.1 Optical Fiber Cable Design

The typical design of an optical fiber cable is with loose fibers inside a thixotropic gel filled metallic tube covered by a protective jacket. Be aware that some equipment utilizing the optical fiber may require a tight buffer design.

When integrated in a three-core cable, the optical fiber cable does not require armoring, though some manufacturers prefer to include this to add mechanical strength to the metallic tube. When installed separately or in a bundle with an HV single core cable(s), the optical fiber cable should be armored to provide mechanical strength, and a degree of mechanical protection against impacts and crushing. Methods for determining possible breaks in the metallic tube surrounding the fibers should be specified by the cable supplier.

The selection of materials in the optical fiber cable is important as this has been identified as a cause of prior failures in three-core cables. Recent recommendations are use of high electrical resistance materials for metallic tube and armor, such as stainless steel, and to use semiconducting material for the protective jacket. These measures will reduce the induced voltage in the optical fiber cable metallic parts and consequently reduce the probability of damage to the power cores if there is a break in the optical fiber metallic tube.

The metallic parts of the optical fiber cable should be solidly earthed at both ends.



Figures: Typical design of an optical fiber cable (left), Typical design of an armored optical fiber cable (right)

6.4.2 Optical Fiber Types

Communication grade fibers are usually used for the communication and control of offshore wind farms. Because of the distance range of the export and IACs, single mode fibers are generally used.

For monitoring purpose, single mode or multimode fibers can be used depending on the distance range on which the cable should be monitored.

6.4.3 Optical Fiber Cable Assembly and Construction

Fibers are first individually marked or colored for identifications with a specific color code according to international standards. Note that differences may exist between international and North American standards regarding color coding and requirements of various ISOs or other interfacing entities may vary. They are then inserted loose in a metallic tube as a bundle of typically 12 to 48 fibers (more fibers can be inserted in a tube if required but increase complexity). The metallic tube is filled in with water-blocking and hydrogen scavenging material. The metallic tube is then covered by a jacket for additional protection.

6.4.4 Integrated Optical Fiber Cable in 3-Core Cables

When a three-core submarine cable is supplied, optical fiber cables can easily be integrated in the interstices between each power phase during the lay-up process. The optical fiber cable is then protected from other power cores with plastic profiles or yarns. This solution offers additional protection of the optical fiber element.

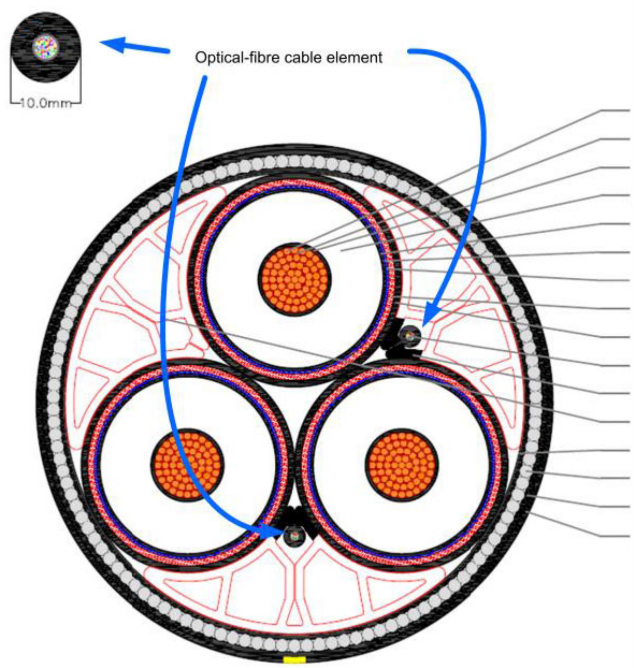


Figure: Integrated optical fiber element in a three-core cable

At landfall, in the OSP or in the WTG transition piece, the fiber optic cable elements are then terminated in a patch panel or spliced to a pre-installed cable. The metallic sheath should be solidly grounded at the ends of the cable.

6.4.5 Optical Fiber Cables with Single Core

When single core cables are used (in HVDC for instance), stand-alone armored optical fiber cables are usually installed in the bundle with the power cable or separately. In this case, the optical fiber cable should be armored with steel wires. The wires can then be covered by an outer serving made of a PE sheath or PP yarns. This design of optical fiber cable is similar to submarine optical fiber cables installed across oceans.

Alternatively, the metallic tube containing the fibers can be inserted in one of the sheaths of the cable, or in the armor by replacing some armor wires. This solution complicates the manufacturing and the handling of the single core cable but has been used in some cases. This solution also limits the number of fibers that can be installed in a single tube given the outer diameter of the tube is limited to the outer diameter of the adjacent armoring wires.

On land, or in the OSP or WTG, optical fiber cables are installed separately, and are usually unarmored except if additional tensile strength is required. Typical land installation is in a duct to facilitate long cable lengths and can be “blown” into the duct. Termination or junctions to these optical fiber cables are typically done by fusion splicing to another cable or to a pre-terminated “fiber pigtail” to eliminate field polishing of fiber terminations.

6.4.6 Cable Monitoring with Optical Fibers

A monitoring system uses an optical fiber as a distributed sensor for monitoring along parts of or the whole power cable. The instrument sends laser signals into the fiber. All optical fibers will return a small part of the laser signal called backscattered signal and parts of this signal will be altered based on the temperature or strain or vibration along the fiber. Reference IEC 61757-2-2.

The backscattered optical signal contains three main elements: Rayleigh, Raman, Brillouin. Each type of backscattered light is created due to different physical phenomena occurring as the laser signal travels through the fiber medium and has different properties that can be used for monitoring purposes. Rayleigh is non-temperature dependent but is used to determine distance along the fiber. Raman is temperature-dependent, and Brillouin is temperature and strain dependent.

Monitoring systems utilize one, two or three of the backscatter elements, or a combination of backscatter types to monitor various parameters.

Cable modelling and system calibration are consequently crucial to obtain a reliable assessment of these parameters.

So, instead of using discrete sensors along the power cable to monitor various parameters, it is possible to analyze various signals, and their variation to have a picture of these parameters along the cable.

Below are the abbreviations of the main monitoring concepts available:

- DTS: Distributed Temperature Sensing
- DSS: Distributed Strain Sensing
- DAS/DVS: Distributed Acoustic/Vibration Sensing
- DOB: Depth of Burial (change over time relative to as built)
- RTTR: Real Time Thermal Monitoring

There is currently a lot of development ongoing in this field, where distance range, spatial resolution and accuracy are steadily increasing. New concepts are also under development to monitor other parameters and link with outside systems (e.g., Automatic Identification System Transponders to DAS systems).

6.5 Cable Accessories

Typical accessories to the electrical system include cable hang-off and termination systems, joints, splices, J-tubes, cable crossings, and cable protection systems near foundation entry points or at crossings. These items should be designed and manufactured in accordance with the cable manufacturer's specifications.

Manufacturer's cable accessories specifications should describe the following (provided this information is not confidential to the manufacturer):

a) the required submarine cable field joints including all materials, equipment and tools for jointing
b) the required underground cable field joints including all materials, equipment and tools for jointing
c) cable terminations including complete oil pressurizing systems, if applicable
d) steel structures for the cable terminations
e) complete cable anchoring arrangements
f) all necessary cable clamps and earthing connections, etc.
g) spare submarine cable repair joints including all materials
h) spare underground cable repair joints including all materials
i) complete spare termination (cable sealing end) including complete oil pressurizing systems, all materials, equipment and tools for termination of the cables
j) cable crossing designs including buried and exposed cables and pipelines, both in service and out of service
k) cable protection systems at transition to foundation entry point(s)

6.5.1 Electrical Accessories

6.5.1.1 Terminations

For AC cables for offshore wind power, three main types of terminations are used depending on the location of the termination i.e., onshore substation, OSS/OSP or WTG and what cable to be terminated i.e., export cable or IACs. Offshore, use of oil in the cable termination should be avoided to reduce the risk of fire and explosion and potential oil spills. Free of oil terminations are often referred as “dry” terminations. Oil-free “dry” plug-in terminations are available up to 420 kV AC.

At the OSP, HVAC export cables may be terminated directly in the switchgear compartment or at a junction box on the cable deck. Alternately, the cables can be jointed to the platform cable that is terminated to the switchgear. For OSPs, most switchgears are insulated by SF6 gas and are referred to as GIS switchgear. The typical GIS termination is made of a male connector and a polymer pre-molded stress cone encapsulated in an epoxy resin insulator. The termination is engaged and installed in a corresponding receptacle in the GIS compartment. IEC 62271-209 and IEEE 1300 provide the dimensions for the design of the GIS cable terminations. Alternative project specific solutions may exist and should be coordinated with the cable manufacturer and installer.

AIS are similar to onshore application and can theoretically be used for HVAC export cables. However due to the significant space for the insulator in air and the large air insulation required distance to the grounded part, they are rarely used in an OSP. The exception is for HVDC (above ±320 kV) applications where the cable is not connected to a switchgear or a transformer. DC GIS terminations currently exist for ±320 kV cables and higher DC voltage GIS terminations are in development. Design of air insulated HVDC terminations on the OSP should plan for minimum free space to ensure a correct insulation distance and indoor closed environment to protect the termination against pollution and salt contamination.

In the WTG, IACs are generally terminated using a plug-in arrangement directly into the WTG switchboard or junction. Sometimes, the switchboard is not physically placed close to the cable hang-off location. In this case, a junction box is installed in the vicinity of the hang-off and jumper cables are pre-installed onshore between the switchboard and the junction box. The IACs are then connected using plug-in arrangements. This solution reduces the length of cable needed to be pulled into the WTG.

Plug-in arrangements also referred to as connectors can be found in “elbow” shape for single cable connection or “T” shape for piggy-backing connection on the same connection point. They are available in the market for voltages up to U_m=52 kV and use interfaces described in CENELEC EN 50180 and EN 50181. T-connectors allow for cable branching.

Also please see the following references:

- For HVAC: CIGRE TB 610
- For HVDC: CIGRE TB 852
- DNVGL-RP-0360

Historically, the IACs connecting the WTG string to the OSP have been terminated in the same fashion as within the WTG, using junction boxes and pre-installed jumper cables. This solution is available for voltages up to U_m=72.5 kV. However, with the voltage level increase of the WTG and IACs to U=66 kV, it is now possible and cost efficient to connect the inter-array cables directly in the switchgear using GIS terminations in the same fashion as for the export cables.

At the onshore substation, the cable terminations can be standard onshore cable terminations, such as polymeric or ceramic air or oil insulated terminations or GIS terminations depending on the system design chosen.

Terminations should be type tested and when required pre-qualified as part of the submarine power cable system as described in section 8.1 of this document and in CIGRE TB490.

6.5.1.2 Joints

Submarine power cables for the offshore wind power industry, and especially export cables, are generally required to have lengths exceeding the maximum production capacities of power cable factories. For the contractor to deliver cables as one complete length or as lengths that fit the limitation of the CLV, joints are required.

There are two families of joints: flexible or rigid joints.

Flexible joints are joints where each different cable layer is manually reconstructed to the dimension of the existing cable. Once completed, factory joints have the same electrical and mechanical properties as well as approximately the same dimensions as the original cable. Flexible joints can be handled with the same equipment and in the same fashion as the original cable. Care should be taken regarding allowed maximum values of tension and torsion in the vicinity of the flexible joint. Typically, factory joints are electrically tested in the same manner as the original cable, reference to CIGRE TB 490.

Rigid joints are joints made of prefabricated elements which provide electrical continuity of the cable. The original conductors are connected by means of connector ferrules. The insulation is made of pre-molded insulation sleeves which are slid over the connector ferrule. The rest of the power core layers are made of prefabricated sleeves or tapes. Once the power core joints are completed, the power core bundles are generally placed in a metallic cylinder where the cable armoring 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.

If FO elements are present, they are jointed in a splice box placed in the metallic cylinder.

Rigid joints are faster to perform than flexible joints because it takes less time to apply the different layers and no curing process is required for the insulation.

Refer to CIGRE TB 610 for more details on flexible and rigid joints, or CIGRE TB 490 Section 4.1.1, Figure 6 for a cross sectional sketch of a factory/flexible joint.

In the offshore wind industry, both flexible and rigid joints are used on cables for different applications. The following sub-sections define the types of applications for the joints.

6.5.1.2.1 Factory Joints

Factory joints are flexible joints performed at the cable manufacturer. Because of production length limitations for the power cores, these joints are used to allow delivery of the longest or complete delivery length of submarine power cable. Usually, these joints are performed before the power cores are laid-up together. However, in some cases it is possible but laborious to perform factory jointing after the completion of the last manufacturing process i.e., after armoring.

For HVDC cables, since there is no lay-up process, factory joints are typically made before the armoring process.

Factory joints can be used to connect power cores with different designs, i.e., different conductor cross sections, conductor materials or metallic screens.

6.5.1.2.2 Field/Repair Joints

Field joints and repair joints are rigid joints (solid dielectric insulation) and utilize the same components. For MI insulated cables, the field joints and repair joints are the same.

Repair joints are typically used in the event of cable damage and are performed on armored cables. As they are usually performed on board a vessel, to limit the duration of the repair operation, repair joints are usually pre-molded rigid joints.

Field Joints are used to connect two delivery lengths together offshore. They are rigid joints and follow the same design principle as repair pre-molded joints.

These joints can be used to connect cables with different designs, i.e., different conductor cross section, conductor material, metallic screen, or armor.

In case of HVDC cables with MI insulation, repair joints are flexible joint, where the conductors are welded wire by wire and the insulation system is manually re-instated layer by layer.

6.5.1.2.3 Onshore Transition Joints

In most of the cases the connection point for the export cable is inland and single core land cables are used to connect the submarine export power cable to the onshore substation. Onshore transition joints are used to connect the armored three core submarine cables to the single core land cables. The submarine cable armor is mechanically secured in an armor clamp and the power cores are unlaid. Each power core is then jointed to a single core land cable. Onshore transition joints are typically made in a joint bay located close to the shoreline.

Onshore transition joints can be used to connect power cores with different designs, i.e., different conductor cross sections, conductor materials or metallic screens.

Bonding schemes need to be considered at this joint location. For 3-core AC submarine cables the bonding is typically a solid bonded scheme. Land AC cables can be Solid, Single point or Cross bonded.

All joints should be type tested and when required pre-qualified as part of the submarine power cable system as described in section 8.1of this document and in CIGRE TB 490 and CIGRE TB 623.

6.5.2 Mechanical Accessories

6.5.2.1 General

In general, steel components should be designed in accordance with a recognized structural design code, e.g., ISO 19902 or DNVGL-ST-0126, unless owner requirements specify otherwise

Components of composite materials should be designed, manufactured, and tested to industry standards such as DNVGL-ST-C501.

For components regarded as lifting equipment, an additional safety factor is required. This is addressed in ISO 19901-6 and DNVGL-ST-N001, section 16. Also see OCRP-1 regarding lifting equipment.

Design criteria and guidance for structural design of mechanical cable accessories may be found in DNVGL-ST-0359.

6.5.2.2 Rigid / Repair Joint

A rigid repair joint should be designed for the maximum loads, i.e., tension and bending moment, expected during installation and/or recovery, accounting for dynamics due to hydrodynamic loads. See section 6.7.3 for guidance with respect to installation analyses and determination of design loads.

The armor terminations in the repair joint should be designed and tested as described in section 6.5.1.2.2

To prevent cable over-bending at the joint interface during installation, the application of a bend restrictor/stiffener or guide at each end of the repair joint should be considered. It should be demonstrated through analysis that the capacities of the cable, joint, and bend restrictor/stiffener are not exceeded during installation.

See sections 6.5.2.6 for further guidance with respect to design, manufacture and testing of bend restrictors and bend stiffeners.

6.5.2.3 Cable Armor Hang-Off

A cable armor hang-off or armor wire hang-off should be designed to support maximum anticipated cable tension and potential compression during installation and service, as applicable. The hang-off should be able to support the cable while not reducing the functionality of the cable and be designed to last for the service life of the power or fiber optic core. Hang offs are required where an armored cable is to be connected to a fixed point such as, the top of a J-tube, a transition joint from submarine cable to land cable, and at the end of a land fall HDD to name a few examples. There are specific designs of hang offs. Hang-offs are required for all armored cables e.g., three-core submarine, single core submarine, and armored fiber cables. Depending on the water depth the cable may have multiple layers of armor wires and the hang-off should be designed for the specific application. There currently is no industry standard for the design of the hang-offs.

Their design should be qualified through tests to demonstrate that functionality is maintained when subjected to combined cable tension and corresponding curvature at the hang-off interface during installation. Where relevant, e.g., for some pre-tensioned hang-off designs, the qualification tests should also demonstrate that axial compression (negative cable tension) or a reduction in cable tension will not reduce the tension capacity of the cable hang-off.

6.5.2.4 Pulling Head

A pulling head is, in general, regarded as lifting equipment, requiring an additional safety factor, see section 6.7.3. Under certain conditions, however, the so-called consequence factor may be discarded, see DNVGL-ST-N001.

The robustness and adequacy of pulling heads should be proven by testing, and certified and designed with sufficient strength for the intended application.

6.5.2.5 Chinese Fingers / Cable Stockings

Chinese fingers (also called cable stockings or cable slings) are typically applied to cables as an installation aid, e.g., in relation to cable pull-in or temporary hang-off, in which case they should be regarded as lifting equipment.

Design, manufacture, and testing of Chinese fingers or cable slings should be performed in accordance with accepted industry standards.

The wire ropes should be designed with appropriate design and safety factors.

6.5.2.6 Bend Restrictors

The main purpose of a bend restrictor (also called bend limiter) is to limit cable bending radius at a connection point, e.g., at each end of a rigid repair joint. A bend restrictor is typically designed to withstand a certain moment at a given locking radius. Care must be taken to consider thermal impacts on cable due to bend restrictors and/or stiffeners. Note that a bending restrictor mitigates overbending but a bending stiffener mitigates fatigue; therefore they have different geometries. Refer to CIGRE TB 610 Section 9.3.1, for bend stiffener information.

Design, manufacture, and testing of bend restrictors should be performed in accordance with accepted industry standards.

6.5.2.7 Cable Protection Systems

A cable protection system may consist of different types of components and materials, assembled such that they provide protection of a certain length of cable from hydrodynamic loads, wear, excessive fatigue damage, dropped objects or other influences that could damage the cable.

As no design code specifically aimed at cable protection systems is currently available, each type of component should be designed in accordance with suitable requirements. See section 6.7 for guidance.

6.5.2.8 Installation / Hang-Off Clamps

Cable diameter will typically decrease as the cable is tensioned. The change in diameter depends on the cable design; A three-core (AC) cable will typically be more susceptible to a diameter reduction than a compact DC cable.

When a radial load is applied to the cable, e.g., from a clamp, the polymer materials in the cross-section, such as conductor insulation, sheaths, and fillers, will typically deform. Subject to the applied load, and thus amount of deformation, the polymer materials may creep/relax, potentially reducing the resistance to the applied clamping force.

Thus, both an increase in cable tension and creep effects may result in a reduction in the contact force between a clamp and a cable. It is essential that these effects are considered in design of installation and hang-off clamps to prevent unexpected cable slippage.

Temperature should also be considered, as it may affect the rate of creep/relaxation and friction between the clamp and load-bearing elements (e.g., armor wires) of the cable.

To account for manufacturing tolerances (in both cable and clamp) and uncertainties in material properties, a safety factor of 1.5 should be applied when determining minimum required clamp squeeze load to support a certain cable tension.

Tests should be performed to verify clamp capacity, considering long-term (creep/relaxation) effects. Reference to IEC 61914 for testing of cable clamps.

Temporary hang-off may be designed with lower margins. It should be considered that permanent and temporary hang off may have different requirements depending upon time frames considered.

See API specification for subsea umbilicals, as well as DNVGL-ST-N001 for further details.

6.5.2.9 Cable Sealing End Caps (Long Term; Short Term)

Cable sealing end caps are used to seal off the cable for submerged placement waiting for other equipment to become available for cable installation (i.e., substation, joint, etc.). Sealing end caps must be waterproof and designed to handle the pressures that accompany the installation depths. Short term is typically six months or less than two years. No industry standard adequately addresses the requirements for this, but it is a generally accepted requirement that no water will enter the sealing end for the time period stated.

6.5.3 Dynamic Cable Accessories

Dynamic Cables are used in applications (i.e., floating structures) where the cable system will be exposed to and must operate in an environment where the cables will be moving due to wind, wave and currents over the entire operating life of the cable system.

6.5.3.1 Bend stiffeners

The main purpose of a bend stiffener is to distribute cable bending over its length and thereby reduce fatigue damage at the cable connection, e.g., to an offshore structure. As opposed to a bend restrictor that limits cable bending radius, a bend stiffener serves to increase cable bending stiffness and thus reduce bending at a connection.

A bend stiffener should be designed to prevent excessive bending of the cable, considering maximum expected tension and angle at the cable (and bend stiffener) connection point during installation and in service, as applicable.

As a bend stiffener tends to become softer with increasing temperature, the most conservative (minimum) cable bending radius is normally found for the maximum temperature. Likewise, maximum interface loads at the connection point are normally found for the minimum temperature.

As a bend stiffener tends to become stiffer with decreasing temperature, maximum interface loads at the cable and bend stiffener connection point are normally found for the minimum design or installation temperature, whichever is relevant. Likewise, the most conservative (minimum) cable bending radius is normally found for the maximum temperature. In some cases, however, minimum cable bending radius may be found just outside the bend stiffener region. Therefore, both maximum and minimum design or installation temperature, whichever is relevant, should be considered in design.

Design, manufacture, and testing of bend stiffeners should be performed in accordance with specification for subsea umbilicals.

6.5.3.2 Buoyancy modules

The application of buoyancy modules to the cable may be necessary to establish a specific dynamic cable configuration. It is essential that these buoyancy modules are rated for the water depth at which they will operate, and that loss of uplift (due to water ingress) throughout the service life of the cable is accounted for in design.

Design, manufacture, and testing of buoyancy modules should be performed in accordance with specification for subsea umbilical.

6.6 Water Blocking

6.6.1 Water Blocking Materials and Applications

The phenomenon referred to as water treeing is well known from many years of study. Polymeric insulation systems, when exposed to electrical stress, water (humidity) and contamination (particles, voids, semi-con/insulation interface defects) can result in deterioration of the cable dielectric system. Several methods are used to mitigate the formation of water trees with varying effectiveness. Limiting water penetration by the application of water blocking materials reduces tree growth to minimum levels.

Dry design cables are produced by using an impervious outer metal layer to prevent RWP of the cable core. This is the dominant design used for high voltage transmission cables but is also used extensively at MV levels. In conjunction with the outer radial water barrier, the cable must also be protected from LWP in the event the radial barrier fails.

There are several accepted methods for type testing of LWP and RWP for medium and high voltage power cables and joints such as IEC 63026 and CIGRE TB 490. The type test methods noted in these documents are very similar: TB 490 references tap water or salt water with salinity relevant for the intended application. IEC 63026 references tap water or 3.5% by weight NaCl solution. For testing the LWP and RWP, reference is made to CIGRE TB 490, section 8.7, CIGRE TB 623, section 5.4 or IEC 63026. Note: these requirements may vary from the component cable core with jacket requirements. Note that CIGRE TB 490, section 8.7 is referenced in the above documents.

It should be noted that the superabsorbent water blocking materials have lower performance levels in ionic solutions such as tap or seawater, compared to their performance in de-ionized water. Artificial Seawater can be formulated using ASTM D1141-98. There is no standard formulation for fresh water as would be seen in normal freshwater lakes or rivers. “Tap” water is not a reliable test fluid. Studies have been conducted that highlight the variability of “tap” water throughout the US. Consideration should be given to formulating a standard ionic solution that simulates fresh water. One such formulation proposed consists of a 3% solution of Artificial Seawater. It is suggested that the salinity used in test water be representative of the installation site.

A variety of materials and application methods are commonly used to provide the water blocking and water penetration protection for the cable.

6.6.2 Conductors

The longitudinal water protection measures required depend on the design of the conductor. With solid conductors, it has been shown that longitudinal water migration along the surface of the conductor, under the extruded semi-conductor layer, can occur. The interstitial spaces within other “stranded” or Milliken style conductors can allow for the longitudinal migration of water within the conductor.

A variety of materials can be used to limit the LWP length within or along the surface of the conductor. These include strand block compounds, superabsorbent powder, and a variety of substrates such as WBT and WBY containing superabsorbent polymers. The thermal stability of the WB material for conductor use is determined via dry aging, as an MV/HV submarine cable with a wet conductor is no longer functional, so there is no current heating of the WB material when wet.

6.6.3 Metal Screen/Sheath

If the cable is cut, the water will migrate longitudinally down the cable due to capillary action if there is no added protection or other mitigation measures. The RWP protection for the cable is provided by an impervious metal screen/sheath. LWP protection must be provided in the area underneath the metal screen/sheath, over the insulation shield. Semi-conducting water-blocking tapes are commonly used in this area to provide LWP protection. The thermal stability of the hydrated gel produced by the tape is important as a damaged cable could continue in service with normal heating of the sheath area. All materials except metals will migrate moisture. The moisture migration rate is a function of many things but mostly the layer thickness, temperature, and time.

6.7 Structural Design of Cables

6.7.1 Mechanical Properties

The cable supplier should, as a minimum, specify the following cable properties:

- Unit mass with empty voids
- Unit mass with voids filled with water
- Submerged unit weight with empty and water-filled voids
- Bending stiffness
- Axial stiffness
- Torsional stiffness

See CIGRE TB 623 for data that should be supplied.

The mechanical properties of polymers vary with temperature, as does the viscosity of bitumen often applied over the armor wires for corrosion protection. Consequently, temperature will affect cable stiffness. To account for worst-case conditions, cable stiffness properties should therefore be specified for both maximum and minimum design temperatures.

As a minimum, cable bending stiffness should be specified for full slip conditions, i.e., assuming no friction between cable components. 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.

Accounting for effects of bitumen in the armor layer(s) will typically yield a higher bending stiffness, which in some cases may improve results, e.g., in the touchdown and bend stiffener regions. A more realistic bending stiffness will also enable simulation of more realistic cable behavior at low tension.

However, bitumen causes cable bending stiffness to not only vary with temperature, but also with the change in curvature and frequency of bending. It is therefore not straight forward to determine a representative bending stiffness for a given condition, nor to simulate realistic cable behavior. Thus, if effects of bitumen are accounted for in the cable bending stiffness specified by the cable supplier, the corresponding temperature, rate of change in curvature and frequency of bending should be specified. The basis for the specified bending stiffness should also be documented by tests.

6.7.2 Structural Capacities

The cables supplier should, as a minimum, specify the following cable capacities:

- Maximum allowable tension, straight pull
- Minimum allowable bending radius, storage and handling (low tension)
- Minimum allowable radius of support/contact surface, e.g., chute, lay wheel, capstan or J-tube bend, at maximum anticipated tension
- Minimum allowable bending radius at maximum anticipated installation tension without support (i.e., free bending)
- Maximum allowable twist per unit length
- Maximum allowable tensioner squeeze load at maximum anticipated installation tension
- Maximum allowable axial compression, if applicable

In some projects, e.g., in dynamic applications, it may also be relevant to specify ultimate tensile load.

A design code that specifies design criteria for failure modes related to installation and operation of submarine power cables is currently not available. Although the IEC standards and CIGRE technical brochures specify requirements to electrical performance after the cable has been exposed to mechanical loads, no requirements or guidance to structural design are provided.

The load at which a cable ceases to fulfill its electrical requirements is typically lower than the load at which it fails mechanically. Specified cable capacities in tension and bending should therefore be verified by tests. See CIGRE TB 623, Section 6 for information about relevant tests.

Maximum allowable tensioner squeeze load is a function of tensioner configuration, i.e., number of tracks, as well as pad material, geometry and spacing. Unless allowable squeeze load is specified for the tensioner(s) to be used to install a cable, the cable installer should check if the specified allowable squeeze load applies to the relevant tensioner specifics. If not, the cable supplier should provide the updated parameters for that tensioner. See CIGRE TB 623, Section 6.3 for information about relevant tests.

To prevent the cable from slipping through the tensioner during installation, the cable installer should also specify minimum required track length of a given tensioner configuration and pad design required to support maximum anticipated installation tension. Minimum required track length should account for the viscous properties of bitumen and creep/relaxation of polymer materials, particularly the outer sheath where relevant. See section 7.4.8 of DNVGL-ST-N001 for further guidance. Submarine power cable mechanical design is validated by type testing according to CIGRE TB 623 and agreed upon by all parties involved.

The ultimate tensile load should reflect the condition where the load-bearing components of the cable reach their ultimate tensile strength.

6.7.3 Installation and Operational Loads

CIGRE TB 623 describes the equipment and methods to install submarine cables and also provides in the annexes methods to calculate loads and testing loads to test the cable design for the installation conditions and method that the cable will be exposed to. These loads are based on sea conditions, and water depths along with forces the cables will be exposed to during installations and include factors of safety. The annexes also include the background to the equations to provide for a better understanding of the calculation methods. Comparisons are done between FEM software and measured values from installations to validate the formulas. Some companies use a FEM package called OrcaFlex to simulate the cable response during cable touch down and catenary shape during cable installation.

The following cable related information is typically supplied by the cable manufacture to the installation company based on expected site conditions to assist in the development of the installation plan. This is sometimes developed after discussions between the cable manufacturer and the cable installation company

Voltage Class
Diameter [mm]
Weight in Air [kg/m]
Weight in Water [kg/m]

Coil (C) or Turntable (T)
Route Length [km]
Cables per circuit / number of circuits
Cable Length [km]
Weight [Mt]
Min. handling temperature - factory
Min. handling temperature - joint pit
Min. handling temperature - platform
Min. handling temperature - installation vessel
MBR - Handling in factory or after installation - Complete cable without tension
Handling on cable vessel - Complete cable without tension
MBR Complete cable at full tension
MBR on vessel turntable
Maximum Stack Height
Max Allowed Side Wall Pressure
Max allowed Squeeze pressure for Flat or V-Plates Note:
Max Allowed Tension over Chute with radius
Max Allowed Tension Straight line infinite
Estimated Installation conditions
Max laying depth
Significant wave height Hs
Wave period
Friction coefficient over fix chute, if any
Bending radius, chute or wheel
"Calculated tension based on installation conditions above (Cigre TB 623)"
Laying
Recovery

7 CABLE PROCUREMENT & INSTALLATION SERVICES

7.1 Contracting Strategies and Arrangements

It is recommended that project developers design their contracting and procurement strategies as a precursor to establishing contract scopes of supply for manufacturing and scopes of work for detailed engineering, construction, and installation to ensure that all interfaces are fully understood and accounted for across contracts, subcontracts, and purchase orders.

There are several contracting arrangements that can be employed depending on the project's preferences for contract structure, project management, and interface management, and how contractual liability is assigned. Some typical options for contracting are summarized below, although these are by no means all inclusive:

- One Engineering, Procurement, and Construction (EPC[7]) contractor for cable supply and installation:
    - This may be one entity, such as a cable manufacturer who also is able to provide installation services. Some small services such as HDD may be subcontracted by the EPC.
    - This could be a joint venture or preferred partnership between two entities (a cable manufacturer and an installation contractor), or with one entity acting as Tier 1 and the other as Tier 2.
    - If the installation contractor is the Tier 1 entity, the contract could be set up to request the Tier 1 to procure the cable supply scope (and possibly other scopes such as HDD) with a competitive tender.
- Separate Tier 1 contractors, for cable supply and installation:
    - This arrangement would have the cable manufacturer as Tier 1 and an installation contractor also as Tier 1, with the project itself (i.e., the owner, owner's engineer, or engineering and project manager provider) acting as the General Contractor and managing the interfaces between the two entities.

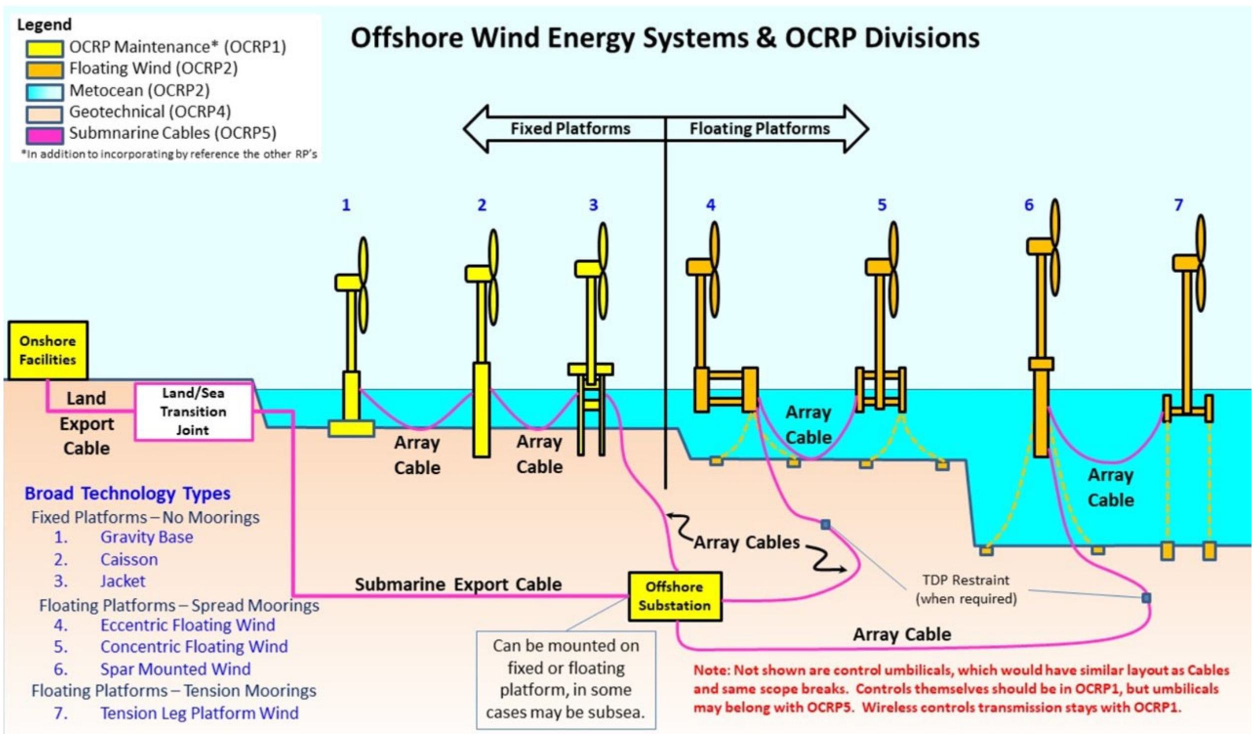
Typically, services such as HDD are subcontracted to local contractors. Further subcontractors may be cable accessories, jointing works, and systems such as DTS/DSS/DAS.

[7] Sometimes referred to as Engineering, Procurement, Construct, Installation (EPCI)

7.2 Interface Management

Across an offshore wind energy development, there exists system level interfaces between the offshore support structures (foundations) which support the wind towers and the submarine cables, whether IACs, between individual WTGs, or between the offshore array and onshore tie-in, from the OSS to the onshore facilities. The below diagram illustrates the overall system and interfacing areas of coverage across the suite of OCRP documents.

1. Key system interface descriptions are listed below: Onshore Facilities – pull in termination end of Cable scope, land/sea transition joint.



2. Offshore Substation – Interface point will occur defined by platform type, submarine cable interface via HV connector with mating point included in a gas insulated switchgear (GIS)
3. Fixed Turbine Platforms – Interface point at cable pull-in head and includes hang off clamp and/or flange mounted upon receiving structure. Design loads imposed upon structure and allowable bend radii provided as interface information by the submarine cable group. Cable J/I tube design with reference to cable loads under scope of platform group.
4. Floating Turbine Platforms – Interface point at cable termination and hang off support (both in Cable scope); loads and porch materials interface with platform. Common cross reference for cable approach path and mooring interference interface requirement with hull design group.
5. Other - All subsea connections and electrical flying leads (if required) in Cable scope, include any Touch Down Point (TDP) restraint required.

The following table outlines some key interface points to be defined as part of submarine cable system design along with essential parameters relevant to each.

<u>Primary Export Cable Interfaces - Offshore Substation to Shore Crossing</u>

S/N	Physical / System Element	Aspects, Issues, Parameters
1	GIS switchgear in the Offshore Substation (OSS) (or WTG junction box for case of Array Cable)	Design of interface, spacing to make terminations and surge voltage limiters (if applicable)
2	FO termination box in the OSS (or WTG, for case of Array Cable)	Grounding should be included and checked
3	Cable trays in the OSS (or WTG, for case of IAC)	Minimum Bending Radius (MBR)
4	J-tube flange	Dimension and design for hang-off
5	J-tube	Inner diameter, outer diameter, material and radius of the bend for cable design, pull-in head design
6	J-tube entrance	Diameter, bellmouth flare angle, height to seabed for design of Cable Protection System
7	Seabed	Geophysical and geotechnical surveys to determine temperature and type of soil for cable design, and to perform burial assessment and cable routing, UXO survey for cable routing
8	Horizontal Directionally Drilled (HDD) Shore Crossing	same essential parameters as for J-tube
9	Junction Pit	similar to land cables
10	Outdoor Switchgear	similar to land cables

7.3 Supplier Qualification

Projects involving submarine power cables are by nature complex and include numerous risks that can lead to catastrophic consequences e.g., loss of wind farm production and revenue for a long period of time. To reduce the probability of those risks, the first step for any contractor involved in an Offshore Wind project is to have a good and robust Quality Management System in place to demonstrate their ability to perform and deliver quality products and services for such projects. Quality Management Systems should be based on recognized international standards such as ISO 9001 and should set in place all the relevant processes and routines during the contract lifetime.

As part of the Procurement process, certificates are usually provided, and preliminary Project Execution Plan and Quality Plans are provided to describe the way the contractor will perform the project. This includes the Project Organization, role and responsibilities of the main project personnel, quality procedures and processes, and define the relations between the various stakeholders of the project.

Audits are usually performed to verify the Quality Management systems in place, visits to the factories to check that the proper Quality Assurance and Quality Control systems are implemented.

7.4 Product Qualification for Installation/Constructability

Products to be used in offshore wind farms should be qualified for the cable system that they will be used for.

See References below for qualification testing requirements for AC and DC cable systems:

- CIGRE TB 623 Recommendation for Mechanical Testing of Submarine Cables
- CIGRE TB 852 Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to and including 800 kV

8 CABLE MANUFACTURING AND TESTING

8.1 Manufacturing Process Qualification

The qualification of submarine power cable systems includes the following:

- PQT
- TT

These tests are performed on a complete cable system, including the accessories (repair joints, terminations, transition joints) and factory joints for a submarine cable, as per CIGRE TB 490, section 1.1.

For mechanical testing, guidance is included in CIGRE TB 623. All PQT and TT should be witnessed by an independent testing agency.

These tests are performed to:

- Verify and qualify the design of the cable and accessories and interface cable/accessory
- Qualify the manufacturing process, in particular the insulation extrusion line
- Qualify the material used, in particular the insulation material
- Validate the long-term performances
- Simulate the mechanical stresses involved during handling, installation and repair

After a successful PQT and TT, a supplier is qualified for delivering a range of cable systems. The criteria giving the range of approval are described:

- For the PQT:
    - For HVAC: in CIGRE TB 490
    - For HVDC: in CIGRE TB 852
- For the TT:
    - For HVAC, up to Um=72.5 kV: in IEC 63026
    - For HVAC, above Um=72.5 kV: in CIGRE TB 490
    - For HVDC: in CIGRE TB 852

Once successfully completed, these tests do not need to be repeated unless changes are made in the cable or accessories material, or design or manufacturing process as described in the above referenced documents. For ICEA core designs, see footnotes in Section 6.2.3 above, for details covering requirements.

8.1.1 Pre-Qualification Test

The PQT is performed to validate the long-term performances of the complete cable system, with a focus on the electrical and thermo-mechanical impacts on the complete the cable system. PQT should be performed for cable system with voltage level U_m> 170 kV and on cable system with $U_m \leq$ 170 kV with calculated electrical stress at conductor >8.0 kV/mm and/or at the insulation screen >4.0 kV/mm.

For more details on the PQT, reference is made to:

- For HVAC: CIGRE TB 490
- For HVDC: CIGRE TB 852

A test loop including the various accessories to be supplied is mounted and is subject to a test sequence including:

- Heating cycle voltage test
- Lightning impulse voltage test
- Examination of the complete system

The heating cycle voltage test is performed at an elevated voltage (1.7 U_0), for a duration of 8,760 hours.

The typical duration to complete a PQT is between 1 to 1.5 years after the manufacturing of the cable prototype.

An EQT can be performed, in particular for changes on accessories which have already passed a PQT. The test sequence is similar to the PQT, but with a shorter duration for the heating cycle voltage test.

For more details on EQT, please refer to:

- CIGRE TB 490
- For HVAC: CIGRE TB 303 (HVAC Cables)
- For HVDC: CIGRE TB 852 (HVDC Cables)
- IEC 60840
- IEC 62067

8.1.2 Type Test

The TT is performed to demonstrate satisfactory performance characteristics to meet the intended application of the complete cable system (including the accessories, and factory joint for a submarine cable), with a focus on the impact of the mechanical stress on the complete cable system.

For more details on the TT, please refer to:

- For HVAC: CIGRE TB 490
- For HVDC: CIGRE TB 852
- IEC 63026
- IEC 60840
- IEC 62067

A test loop including the various accessories (factory joint, repair joint, terminations) to be supplied is mounted and is subject to a test sequence including:

- Preconditioning Mechanical tests on complete cable system
- LWP/RWP tests
- Electrical tests on complete cable system
- Non-electrical tests

The typical duration to complete a TT is approximately 6 months after the manufacturing of the cable prototype.

8.1.2.1 Mechanical Tests on Complete Cable System

The mechanical tests simulate the handling of the cable during transport, installation, and repair. The following tests should be performed:

- Tensile test
- Tensile bending test
- Coiling test (if applicable)

The values of the mechanical tensions and bending radii should be equal or more severe than the actual installation conditions of the project. The mechanical tests should be performed in accordance with CIGRE TB 623, where also project specific mechanical tests are specified. Subsequent to successful mechanical testing being complete, a full electrical test as required by industry standards should be completed.

8.1.2.2 Longitudinal/Radial Water Penetration Tests

LWP/RWP tests are performed to simulate the longitudinal water penetration in the conductor or under the metal screen, and the radial water penetration on joints. For some of these tests a mechanical and/or thermal preconditioning should be performed on the test sample.

LWP and RWP tests are described in detail in CIGRE TB 490, section 8.7, CIGRE TB 623, section 5.4 or IEC 63026. Note: these requirements may vary from the component cable core with jacket requirements.

8.1.2.3 Electrical Tests

The following electrical tests should be performed after the mechanical tests:

- Partial Discharge test at ambient temperature
- tan(δ) measurement (can be performed on a separate sample)
- Heating cycle voltage test
- Partial Discharge test at ambient temperature and at elevated temperature
- Switching impulse voltage test (only for voltage level U_m>300 kV)
- Lightning impulse voltage test followed by power frequency voltage test
- Examination of the cable system and accessories

The heating cycle voltage test is performed at an elevated voltage (2 U_0), which is higher than the PQT, but on a shorter duration (20 days).

Electrical tests and sequence of tests are described in detail in the standards and recommendations listed above.

8.1.2.4 Non-Electrical Tests

Non-electrical tests are a series of tests to verify the construction of the cable and to determine the properties of various materials used in its fabrication, as well as looking at the effect of ageing on these properties.

Non-electrical tests are described in detail in CIGRE TB 490, section 8.9.

8.2 Quality Assurance and Quality Control

At the start-up of a project, a Quality Plan is written by the contractor. It includes all the activities linked to Quality Assurance and Quality Control to be performed during the project, such as risk reviews and assessments for the various steps of the project.

For the manufacturing, an ITP (to be agreed upon between contractor and customer prior to the start of manufacturing) is developed regrouping all the tests to be performed during the manufacturing of the cable and accessories as well as the test levels and acceptance criteria for each test. It also includes the different inspection codes (e.g., Review, Hold, Witness) which allows the customer to have quality control over the product manufactured by the contractor.

These tests can be divided in two main types:

- Routine tests
- Sample tests

Routine and sample tests are performed during the manufacturing of a cable to check and ensure the quality of the cables and verify that processes are according to specifications.

Routine tests are performed on the cable, factory joints and accessories to be delivered at various steps of the manufacturing to check that parameters are in accordance to specified criteria. For instance, routine tests can be a HV test after screening to check the quality of the insulation on an extruded length. Example of electrical sample tests can be PD-test and lightning impulse, or non-electrical tests as outlined in section 7 of CIGRE TB 490.

For more information on Routine Test, please refer to:

- CIGRE TB 490
- For HVDC: CIGRE TB 852

Sample tests are performed on sample of cable during various steps of the manufacturing. For example, it can be a piece of conductor to check the electrical resistivity or start and stop samples of the insulation extrusion to check that various parameters are in accordance to specified criteria.

For more information on Sample Tests, please refer to:

- For HVAC: CIGRE TB 490
- For HVDC: CIGRE TB 852

The ITP also includes the FAT (see Section 8.3), and the post load-out tests, which may constitute a transfer of responsibility between the cable manufacturer and the cable transporter (if applicable).

Before the start of the manufacturing, the ITP, (including inspection codes) should be agreed and approved by all parties.

8.3 Factory Acceptance Testing

The FAT are routine tests performed after the completion of the cable manufacturing and prior to delivery. Tests in accordance with international standards are performed to validate the quality of the complete cable delivery and accessories at the end of the manufacturing before they are shipped out from the factory. They are performed to check and confirm that each delivery length is in accordance with the specified requirements. Tests on the power phases and on FO elements are performed together with some dimensional checks. Because of the generally long length of submarine cables, large testing capabilities are required to perform the electrical test (i.e., power frequency voltage test) for the complete delivery length.

The FAT constitutes an important milestone in the project and are usually witnessed by the Client.

Reference is made to CIGRE TB 490, IEC 63026, IEC 60840, and IEC 62067 for details on the test to be performed for an FAT.

8.3.1.1 Inter-Array Cables

Tests on new installations are carried out when the installation of the IAC system has been completed to verify the overall cable system condition prior to operation.

8.3.1.2 DC Voltage Test of the Over-Sheath (if applicable)

The voltage level and duration specified in Clause 5 of IEC 60229 should be applied between each metal sheath or metal screen and the ground.

8.3.1.3 Time Domain Reflectometry for future fault locating

A TDR measurement could be performed for engineering information.

If TDR equipment is to be used with the cable link it is advisable to perform a TDR measurement to obtain a “fingerprint” of the wave propagation characteristics of the cable.

9 CABLE INSTALLATION

9.1 Installation Engineering and Analysis

9.1.1 Main Principles

In general, an installation operation should be planned such that the structural capacities of the cable are not exceeded. In practice, this entails ensuring an acceptable probability of exceeding the structural capacities of the cable, see section 6.7.2, as the environmental loads acting on the cable are random in nature.

An acceptable probability of exceeding cable capacities should be ensured by applying a recognized standard for identifying critical operations and determining relevant design loads, e.g., DNVGL-ST-N001, section 7.

The basic principle is that an installation operation should be engineered and planned such that the cable may be brought into a safe condition before the limiting weather conditions for the operation are exceeded. A safe condition is one in which the cable acceptance criteria (e.g., allowable combinations of tension and bending radius) are not exceeded, and may be established by:

- completing the operation,
- reversing the operation,
- abandoning the operation, or
- establishing a suitable stand-by configuration.

In cases where the duration of an operation, including contingencies, exceeds 72 hours, excessive weather conditions should be planned for, and contingency procedures developed accordingly. Guidance with respect to planning of marine operations can be found in DNVGL-RP-0360, section 2.

9.1.2 Engineering Process

To ensure that the target probability of exceeding cable capacities during installation is maintained, all critical steps of a cable installation operation should be identified and analyzed.

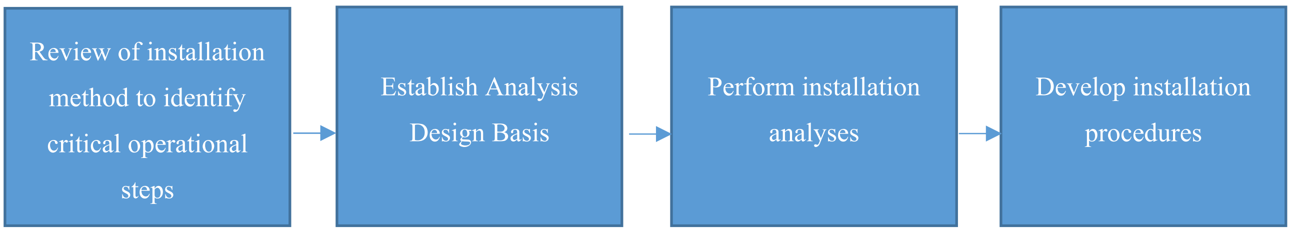
Once critical operational steps have been identified, an analysis premise should be established that describes:

- Critical Activities
- How the operation is controlled/monitored

- Analysis methodology
- Expected output of the analyses

Then, when an acceptable method of performing a critical operational step has been established, relevant installation parameters for that step, e.g., minimum allowable lay-back, should be incorporated in the operational procedures.

The process is illustrated below.



Process to Identify critical operation and prevent damage during installation.

9.1.3 Installation Analyses

Installation analyses should be performed to determine limiting weather conditions for each step of an operation. These analyses should demonstrate that cable loads are within allowable limits and establish relevant installation parameters (e.g., minimum allowable lay-back) to ensure that these limits are not exceeded.

9.1.4 Operation Procedures

Operational procedures should 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 should be clearly stated in the operational procedures, also considering personnel safety and the capacity of installation equipment.

Once information about the cable system, its interfaces and the installation spread are available to the project, the installation process can be engineered to account for the design tolerances, the applicable rules for marine operations and associated operational limiting conditions, depending on the limits for cable handling operations. The installation design should thereby demonstrate that the cables can be installed safely using the intended marine spread and within the allowable limits.

Cable and installation design are interdependent processes and any changes to one is likely to have an impact on the other. Therefore, it is crucial that the scope of the analysis is agreed between relevant parties from the outset, to avoid lengthy engineering delays. The installation analysis design basis is thus a key engineering document for the offshore construction phase.

The installation analysis design basis should address all phases of the cable installation operation including contingency and repair scenarios and should consider both static and dynamic design loads. Scenarios to be addressed should include but not to be limited to:

- Cable storage, load-out and transport
- Cable laying in all environments i.e., landfall, onshore/inland, nearshore and offshore (including infrastructure crossings)
- Cable pull-in at the landfall and at offshore structures
- Cable burial, including burial tools and their characteristics
- Cable protection by non-burial methods
- Remedial protection where/if needed due to too shallow burial
- Cable abandonment and recovery
- Stand-by and cable repair
- Cable joint over-boarding and landing

The installation analysis design basis should identify all critical steps of the installation operation and describe what analyses will be performed to demonstrate that cable integrity may be maintained throughout the installation operation. Analysis methodology should be described, and the basis for the analyses specified and/or referenced, including relevant details of cable, cable accessories (e.g., end terminations, bend restrictors etc.), cable route, vessel and installation equipment.

The installation design should dictate the acceptable operations envelopes to be adhered to during construction to ensure the integrity of the cable is maintained, for example:

- Conformity to mechanical limits of the cable (e.g., minimum bend radius, maximum allowable sidewall pressure, maximum allowable tensions etc.) for all cable handling equipment such as cable engine tracks, chutes, quadrants.
- Weather operating criteria for managing the cable catenary for selected installation spread under different scenarios (as outlined above)
- Laying parameters (e.g., minimum lay angle, maximum lay tension, minimum layback) to be maintained along the cable route

The outcome of installation analyses should be reflected in the installation manual, specifications and drawings.

Further guidance is provided in:

- DNVGL-RP-C205 Environmental Conditions and Environmental Loads
- DNVGL-ST-N001 Marine operations and marine warranty
- CIGRE TB 610 Offshore generation cable connections
- CIGRE TB 623 Recommendations for mechanical testing of submarine cables

9.2 Electrical Tests Prior to and During Cable Installation

Electrical tests are normally performed prior to installation to assure that the cable was not damaged during transportation.

9.2.1 Pre-Load Out Tests

To be performed after the FAT in case of any cable movement, for example, if required by contract, prior to transfer of ownership of the cables.

- DC voltage test of the over sheath: The voltage level and duration specified in Clause 5 of IEC 60229 should be applied between each metal sheath or metal screen and the ground. (Note only if over sheath is nonconductive with outer conductive coating)
- TDR: it is advisable to perform a TDR measurement to obtain a "fingerprint" of the wave propagation characteristics of the cable and to find possible irregularities. See CIGRE TB 773
- Optical Time domain reflectometry (OTDR): In case optical fibers are integrated in the cable, a "picture" of the optical cables taken with OTDR equipment may be useful in locating faults now and in the future.

9.2.2 Monitor During Load-out

- Constant visual inspection during load out of the cable
- Video monitoring
- Continuous OTD

9.2.3 Post Load-Out Tests

See 9.2.1 for more clarification. To be performed after the load out from the factory in case of any cable movement, for example, if required by contract, after transfer of ownership of the cables.

- DC voltage test of the over sheath: The voltage level and duration specified in Clause 5 of IEC 60229 should be applied between each metal sheath or metal screen and the ground. (Note only if over sheath is nonconductive with outer conductive coating)
- TDR: it is advisable to perform a TDR measurement to obtain a "fingerprint" of the wave propagation characteristics of the cable and to find possible irregularities.
- OTDR: In case optical fibers are integrated in the cable, a "picture" of the optical cables taken with OTDR equipment may be useful in locating faults now and in the future.

9.2.4 Post Pull-In Tests

To be performed after the pull-in to the terminating or interfacing facility in case of any cable movement, for example, if required by contract, after installation of the cables.

- DC voltage test of the over sheath: The voltage level and duration specified in Clause 5 of IEC 60229 should be applied between each metal sheath or metal screen and the ground. (Note only if over sheath is nonconductive with outer conductive coating)
- TDR: it is advisable to perform a TDR measurement to obtain a "fingerprint" of the wave propagation characteristics of the cable and to find possible irregularities.
- OTDR: In case optical fibers are integrated in the cable, a "picture" of the optical cables taken with OTDR equipment may be useful in locating faults now and in the future.

9.2.5 Pre-Termination Tests (pre-routing)

- Phase verification of the power cores to ensure that the individual phases (A, B, C for AC cables and Positive and Negative Pole for DC cables) will connect to the proper phase of the equipment.

9.2.6 Post Termination Tests (post routing)

- DC voltage test of the over sheath: The voltage level and duration specified in Clause 5 of IEC 60229 should be applied between each metal sheath or metal screen and the ground. (Note only if over sheath is nonconductive with outer conductive coating)
- TDR: it is advisable to perform a TDR measurement to obtain a "fingerprint" of the wave propagation characteristics of the cable and to find possible irregularities.

9.3 Vessel Installation Spread

9.3.1 Cable Installation Vessels Requirements

Depending on the available water depth, there are presently three main options for a cable installation platform:

- Shallow water barge/vessel capable of grounding out: 0m to 6m
- Main installation barge—minimum 6-point anchor mooring system or DP0 Class: 6m to 50m. Note some main installation barges can go in shallower water than 6m. and deeper water than 50m depending on vessel design
- Main installation vessel—DP2 Class or better: usually over 8 to 10-m water depth and sufficient under keel clearance

Correct selection of the main installation vessel and ancillary equipment is essential to successfully install the offshore wind facility cabling and is highly dependent on a detailed awareness of site conditions combined with installation timetables and local environmental considerations. On larger-scale projects, the likelihood is that the installation solution will be made up of a number of the vessel types listed. In addition, the limited global supply of some types of installation vessels will add complexity to project scheduling.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.5
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.2.2
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables - Section 3.3.3

9.3.2 Support Vessels

Depending on chosen installation method, stage in the project, etc. a significant amount of support vessels might be needed to ensure progress, quality, and safety in the project.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.5
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.2.3

9.3.3 Positioning Systems

The installation barge/vessel should have a position/heading keeping system able to maintain a desired position/heading within the accuracy and reliability required for the planned operation and the environmental conditions.

The positioning/heading reference systems should be capable of operating within the specified limits of accuracy and calibrated prior to start of the installation operations.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.5
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.2.2
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables - Section 3.3.3

9.3.4 Cable Handling and Installation Equipment

Cable handling and installation equipment should meet applicable statutory requirements. Certificates for the equipment, valid for the operations and conditions under which they will be used, should be available on board for review. This only applies to installation aid and appliances and is not permanently applied to the cable system.

Please see the following references:

- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.2.5
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables - Section 6.1

9.3.5 Cable Burial Equipment

Different cable protection techniques are suited to different project characteristics and matching the right technique to the project is important. The most common tools for burial are described below, along with some advantages and disadvantages of each. However, it should be noted that the choice of tool is generally determined by matching the ability of the tool to achieve the required cable burial depth in the seabed conditions encountered along the route. The seabed along the cable route may need to be prepared for the burial tools to allow burial. Please note that the nomenclature for the various cable installation tools varies from manufacturer and region, confirm that the names for the tools are being properly communicated in the discussion between the parties.

In the past before the development of more remotely operated equipment, and in shallower water depths, human professional divers were used to watch the cable installations, and in some cases to actually use tools such as jetting stingers to accomplish the burial of the cable. Current practice is in most cases to use remotely operated and monitored equipment and to minimize the use of divers. This is especially more prevalent in offshore installations. The main driver is related to safety and the protection of risking human life. Many current projects have strict limits on use of divers and some projects forbid the use of divers. Most modern CLV's have ROV's on board with operators to replace divers. The offshore oil industry has developed rigorous standards defining safe diving operations and procedures.

9.3.5.1 Cable Plows

Plows use mechanical force to make a trench. Typically, this is used for simultaneous lay and burial with the cable passing through the plow share and emerging between the bottom of the plow share and a depressor. Therefore, the plow makes a trench and depresses the cable into it in one pass.

In order to reduce the towing force some newer generation plows have jet capabilities.

9.3.5.2 Jet Sled and Jet Trenchers

Jet sled and jet trenchers are normally used where the seabed material can be fluidized, such as in areas of sand and low to medium strength clays. Jet sleds can be diver assisted or self-loading tools that are towed by the vessel and are not normally instrumented for post-burial survey capability. Some shallow water jet sleds are propelled forward by the momentum of the jets and the chassis are supported at the seabed by rollers. Jet trenchers, however, can be somewhat independent, self-propelled hence may be equipped with navigation, positioning and condition survey instrumentation. Jet equipment is normally surface fed, with water pumps on the barge or vessel in shallow water. More sophisticated systems can have pumps mounted to be used subsea. Surface-fed systems require hoses and umbilicals to run down to the machine. Jet trenchers are generally used as post lay burial methods. Jet sleds can be used both as simultaneous lay and burial method.

9.3.5.3 Mechanical Trenchers

Mechanical trenchers use a wheel or cutting chain to form a trench in which the cable falls or can be depressed. Mechanical trenchers are normally used for high-strength soils and are normally deployed from a support vessel, independent of the lay vessel. These machines are typically self-propelled, tracked and can move independently of the support vessel. The cable is normally loaded into the trencher and the trencher follows the surface-laid cable, burying it as it goes. Alternatively, this equipment may be used for pre-lay cutting.

9.3.5.4 Pre-Cut Trenching

In some cases, a pre-trench can be cut by a plow or a dredging vessel. After the cable is laid the trench can be backfilled.

9.3.5.5 Controlled Flow Excavation/ Mass Flow Excavation

For sandy soils, a CFE or MFE can be used to fluidize the sand and the cable will sink by its own weight in the sand. This method may be used for shorter lengths and specific areas such as where the other types of equipment could not be used.

9.3.5.6 Vertical injector

A vertical injector (sometime referred to as a mas flow vertical injector) may be used for shorter lengths to bury the cable to depths greater than other jetting tools are able to achieve. The tool is usually held in position and the vertical depth is controlled by a crane on a large barge which is moved along the route by multiple anchors pulled by winches. The horizontal installation rate is very slow compared to other tools. The tool is able to bury cable in certain soil conditions up to 10 meters depth. This tool is also used for longer length, in the range of tenth of kilometer. Vertical injectors and dredgers are tools which can be used to achieve deep burial depths if required.

9.3.5.7 Selecting the right burial tool

The choice of equipment and cable installation method (see section 9.1.4) is primarily determined by:

- the seabed soils and environmental conditions envisaged along the cable route.
- the level of certainty of the seabed soil conditions and associated scope and quality of survey data.
- the depth of burial specified by the developer as a result of a cable burial risk assessment and authority requirements.
- permitting requirements – in some cases a project may not be able to use a certain technology due to its effects on the environment.
- the installation method (pre-lay plowing, simultaneous lay and burial or separate lay and burial).

A burial assessment study should take into consideration these various factors and provide a recommendation as to the most appropriate type of tool for the given site.

Further guidance on cable burial equipment is provided in the following documents:

- BSEE TAP-671, Offshore Electrical Cable Burial for Wind Farms: State of the Art; Standards and Guidance; Acceptable Burial Depths and Separation Distances; and Sand Wave Effects
- CIGRE TB 610, Offshore generation cable connections - Section 6.3.6.1
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.2.7
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables - Section 3.4

9.3.6 Mobilization

Before mobilization, procedures for safe operations should be in place. In accordance with the mobilization manual, all equipment needed for the operation should be mobilized, including vessel spread and any other component and/or accessory necessary for the installation phase.

Please see the following references:

- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.2.6

9.4 Pre-Lay Survey and Site Preparation

9.4.1 Pre-Lay Survey

A pre-installation survey of the cable route should be performed, if possible, in addition to the route survey required for design purposes.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.2
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.3
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Annex 3

9.4.2 Route Preparation

The marine survey sets the basis for the route preparation. Normally the survey company explores a cable corridor (agreed from either a pre-survey or sea-maps) wherein the cable should be installed.

Route preparation includes but is not limited to (see section 9.1.4):

- Pre lay grapnel run
    - This step is to remove linear debris and abandoned fishing gear. These Pre-lay Grapnel runs typically do not penetrate very deep into the seabed and are primarily used to clear surface debris that has accumulated along the route.
- Seabed levelling (pre-sweeping)
    - In order to achieve burial, the seabed may need to be prepared to allow the burial tool to pass areas (angles) and increase burial (e.g., due to mobile seabed)
- Boulder relocation
    - Required in case the route engineering cannot avoid boulders on the route preventing lay and burial
- Removal of out of service cables or other abandoned assets such as water siphons, water, sewer, gas and oil pipelines, telecommunications cables etc. This is subject to governmental and owning authority approval and the removals should be carefully planned considering HSE and potential environmental implications.
    - In case there are out of service cables that can be removed to allow burial (see section 3.4)
- UXO investigation and removal where required
    - Depending on the UXO strategy a full UXO survey campaign may be required, and targets identified. Where it is not possible to route around these targets they will need to be investigated and cleared reducing the overall threat to ALARP
- Cable and/or Pipeline Crossings: may include concrete mattressing rock, dumping, polyethylene sleeve, or other appropriate methods as designated in the crossing agreement between parties. It would be expected that each crossing has a specific agreement.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 10
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.3

9.5 Cable Laying

The lay configuration and loads should be controlled to ensure that these are within the design envelope during installation. The configuration and loads may be controlled by various means. These should be clearly described, including allowable ranges for the specific sections of the installation.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 3.4.1 and Section 6
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.4
- DNVGL-ST-N001 Marine Operations and Marine Warranty – Section 7
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.3 and Annex 3

9.5.1 Cable Installation

Cable lay parameters such as minimum allowable lay-back, and maximum allowable and minimum required squeeze should be specified in the installation procedure to ensure that cable integrity is not jeopardized during laying. The full range of water depths along the route should be covered, and lay parameters for a given depth interval should be valid for both maximum and minimum water depths within that interval.

Continuous monitoring of cable touchdown should be performed to verify that specified lay parameters are maintained during laying. Alternative methods of cable monitoring are subject to approval by client and marine warranty.

Effects of an inclined seabed on cable response should be accounted for when establishing lay parameters for a sloping seabed. The risk and consequences of cable slippage should be considered, such as the formation of free spans in or above the slope and buckling at the foot of the slope.

It should be demonstrated that a lay operation may be reversed, i.e., that the tension capacity of the installation equipment is sufficient to overcome friction over the chute or similar to allow cable recovery, if necessary.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 3.4 and Section 6
- DNVGL-ST-N001 Marine Operations and Marine Warranty – Section 7
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.4
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.3 and Annex 3

9.5.2 Weather Stand-by, Abandonment and Recovery

Maximum allowable vessel stand-by without paying out cable to avoid excessive cable fatigue damage should be clearly stated in the installation procedure.

The installation procedure should also specify maximum allowable vessel rotation during a weather standby situation to avoid exceeding the maximum allowable cable twist specified by the supplier.

Lay parameters for a safe abandonment and recovery of the cable under worst-case weather conditions should be specified as part of the contingency procedures. The full range of water depths along the route should be covered, and lay parameters for a given depth interval should be valid for both maximum and minimum water depths within that interval.

Sufficient crane/winch capacity to enable cable recovery should be demonstrated, considering friction loads over chute or similar.

Please see the following references:

- DNVGL-ST-N001 Marine Operations and Marine Warranty – Section 7
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.4.2
- CIGRE TB 610, Offshore generation cable connections - Section 6.2.3

9.5.3 Jointing

Cable lay parameters during cable jointing, e.g., minimum allowable lay-back, should be specified in the installation procedure for weather conditions up to and including the maximum allowable for the operation.

It should be demonstrated that a jointing operation may be completed without causing excessive fatigue damage to the cable, considering wave scatter probabilities and limitations in vessel heading, where applicable.

Emergency abandonment procedures and equipment should be readily available to ensure that the vessel may be brought into a safe condition in the event of an unexpected incident or excessive weather conditions.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.10 and Section 9.3.6
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.4.3
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.6

9.6 Equipment and Preparations

Project specific pull-in procedures should be developed to ensure that the cable is installed safely, without exceeding the cable's mechanical limits, see section 6.7.1. The procedure should be based on analyses of the pull-in operation, accounting for friction and passive soil resistance (see DNVGL-RP-F109), as well as any loads related to connecting or activating centralizers, connectors or similar, where applicable. The cable lay configuration and loads should be controlled during installation to ensure that these are within the design envelope, established as part of the installation engineering (see section 9.1). Project specific pull-in procedures should be developed. The procedure should be based on pull-in design and analysis incorporating dynamic amplification factors. Monitoring of the pull-in operation may involve:

- use of ROV or alternative method to observe cable (or cable assembly) entry into the offshore unit's substructure and pull-in progress
- tension monitoring at offshore unit during cable pulling
- detection of loops and kinks
- close communication between operators on offshore unit (controlling pull-in) and on cable installation vessel (controlling cable pay-out).

Please see the following references:

- DNVGL-ST-N001 Marine Operations and Marine Warranty
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.5.1 and Section 6.5.2
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.3.2 and Section 6.7 for the pulling stocking test requirements

9.6.1 Cable Pull-In Offshore

The cable pull-in operation at offshore platform includes normally pulling of cables onto the platform, hang-off, running the (submarine) cables or cores within the platform, fixing cables to the platform structure and termination of the ends for connection to the GIS.

Required pull-in winch capacity should be determined considering:

- friction between cable/wire and I-tube/J-tube,
- cable contact with I-tube/J-tube at bends, considering stiffness and resistance to deformation as the cable is pulled through a bend,
- maximum back-tension at the I-tube/J-tube exit, accounting for tolerances in vessel positioning and cable configuration, and

- required over-pull to engage a seal/centralizer.

It should be demonstrated that the bending moment resulting in pull-in heads and pad-eyes through a bend during pull-in is within allowable limits, where applicable.

It should also be demonstrated that loads resulting on the I-tube/J-tube during cable pull-in are within allowable limits.

Owing to the congestion typical around the base of offshore platforms, due to the large number of IACs present, it should be considered making only first-end pulls at these platforms. “First-end pull” is the pulling of the first cable end, while the rest of the cable is still on the installation vessel. In case any “second end pull” operations are planned assessments will be required to avoid clashes.

Cable operations on platforms are to comply with the safe handling recommendations of the cable manufacturer, particularly with respect to MBR, maximum SWP, and maximum tensile load. The continuous monitoring and logging of the pulling tension is recorded to ensure it is below the mechanical limits of the cable

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.11
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.5

9.6.2 Cable First End

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.11
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.5.3

9.6.3 Cable Second End

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.11
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.5.4

9.6.4 Cable Fixing

The cable pulling operation at offshore platform includes normally pulling of cables onto the platform, hang-off, running the (submarine) cables or cores within the platform, fixing cables to the platform structure and termination of the ends for connection to the GIS. Cable attachments to structure need to incorporate methods and devices to properly hold the cables for the design life of the cable system while allowing for expansion and contraction of the cables due to thermal cycling and potential fault currents. Additionally, the cable systems must be fixed to support the external forces applied to the cables during the design life. Another consideration for the submarine cable routed on to the tower or substation is the protection against fire (from the cable or other sources if the cable armor is removed and the cable cores are routed in the air. Protection of the cables from solar heating should also be considered

Please see the following references:

- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.3.2
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.5.5
- CIGRE TB 669 Mechanical Forces in Large Cross Section Cable Systems

9.7 Landfall

Landfall conditions can vary considerably, from cliffs to sandy beaches to environmentally sensitive salt marshes, and in each case the level of information required will differ. In addition, the technical solution will be based on the actual conditions and restrictions imposed (e.g., cutting through the sea defense).

There are multiple options which the list below is not all inclusive:

- Open cut trenching
- HDD
- Direct pipe
- Microtunnel

As a rule of thumb open cut solutions are cheaper and faster than HDD solutions. Furthermore, the environmental impact will in many cases be the same or less for an open cut solution compared to an HDD solution. All options should be considered by the designer and best solution for the conditions chosen.

Consideration should be given to whether the landfall has been used before by another party, e.g., gas lines, telecommunications etc., as this could provide valuable information to most cost effectively plan any additional survey works.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 3.1.6 and Section 3.2.4
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.6

9.7.1 Open Cut Trenching

In some situations, it is possible to make a trench with a backhoe and bury the cable or conduit pipe in an ordinary way. In other cases, it is possible to pull the submarine cable in an open trench at the beach/shore without using a pipe as protection. The surveys should help to find the optimal method. On the other hand, each method has also certain surveys required to install the cables correctly.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 3.1.6 and Section 3.2.4
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.6.2

9.7.2 Horizontal Directional Drilling

When the landfall is to be constructed using HDD, prior knowledge of ground conditions and a site investigation program adapted to the geometry of the HDD (depth, length, location of entry and exit points) are crucial to the success of the HDD installation. This is especially critical as HDD near shore areas with fluidized soils can be more challenging than normal onshore HDDs.

Options for the casing material for the landfall are:

- Steel pipe (carbon or stainless)
- PVC pipe
- HDPE pipe

Cable installation (pull-in) tensions into the HDD casing should be monitored to ensure the maximum loads on the cable and installation equipment are not exceeded. Monitoring also has to be performed at the entrance of the cable to the HDD to ensure that cable over-bending is avoided.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 3.1.6, Section 3.2.4 and Section 6.3.5
- CIGRE TB 770 Trenchless technologies
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.6.3
- ASCE Manual of Practice No. 108 Pipeline Installation by Horizontal Directional Drilling
- ASCE Manual of Practice No. 115 Pipe Ramming
- Standard ASCE/CI 36, Standard Design and Construction Guidelines for Micro tunneling
- NASTT Horizontal Directional Drilling (HDD) Good Practices Guidelines
- ASTM F1962 Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipeline or Conduit Under Obstacles, Including River Crossings

9.7.3 Cable Pull In at Landfall

Detailed requirements for the execution, inspection and equipment testing of the shore pull should be specified, considering the nature of the particular installation site.

Pulling heads and other equipment should be dimensioned for the anticipated forces (not exceeding the mechanical specifications of the cable) and provide a secure connection.

Monitoring and measuring devices should be used during execution of the shore pull. Continuous monitoring of the cable tension and pulling force should be performed to verify loads are within allowable limits.

Required capacity of pull-in winch should be documented, accounting for potential soil penetration of the cable and required break-out force after a temporary stop in the pull-in operation.

Effects of wind and current on a floated cable should be accounted for, considering the worst-case vessel stand-off distance at low tide.

A pre-determined safety factor, commensurate with the level of certainty of site conditions and/or operating parameters should be applied to determine required winch capacity to account for tolerances and uncertainties in friction factor.

Contingency procedures for weather stand-by, e.g., visibility/daylight in the event that the operation takes longer than expected, should be developed.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.4
- DNVGL-ST-N001 Marine Operations and Marine Warranty
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.6.4
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.3

9.7.4 Interface with Onshore

The sea/land transition joint bay area should be constructed in accordance with the design documentation. Depending on its location, temporary measures for dewatering may be required. When the necessary length of subsea cable has been pulled in, the cable should be mechanically secured (anchored) in / at the sea/land transition joint bay. The jointing of subsea and land-based cables at the sea/land transition joint bay should be carried out in accordance with the procedure developed for the particular cables and approved by the cable manufacturers. After jointing and testing of subsea and land-based cables, the sea/land transition joint bay should be closed and secured. Where feasible, accessibility to the pit should be retained for the operational life of the project to ensure its maintainability.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.2.2
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.6.5
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.3

9.8 Cable Protection

Different burial tool systems are available in the market designed to bury the submarine cable; new developments are made regularly. The burial equipment used mainly depends on seabed characteristics. The most common burial tools used are mechanical plow and water jetting systems. Plow systems are connected to the host vessel (vessel or barges) and towed.

Some areas will require different protection than burial, such as near the foundations, at crossings and cable ends.

Reference is made to Section 9.3.5for descriptions of cable burial equipment and methods.

9.8.1 Cable Burial

Cable burial can be divided into three distinct solution types:

- Pre-lay trenching
- Simultaneous lay and burial
- Post-lay burial

Each method has its advantages and disadvantages. Pre-lay trenching can be performed off the critical path, and multiple passes are possible, although a wider trench is created initially and a separate backfill pass may be required. Simultaneous solutions reduce the number of vessels that are mobilized, however greater manipulation of the cable is involved. Post-burial de-risks cable installation operations by decoupling cable lay and burial, which can take place at different speeds, and catenary management is less critical. However, mechanical trenchers require cable handling and jet trenchers can have limited success in harder seabed.

Prior to cable installation, the seabed may be pre-prepared for installation / trenching. This would normally involve the removal of boulders that could impede a trencher or plow and or the removal of sand waves creating a channel using pre-sweeping techniques, one of which may be dredging. This seabed preparation ensures that the chosen method of installation and burial will be successful, however it should also be noted that it is not a requirement on flat featureless seabed that exist in many areas.

UXO risk assessment and mitigation is also a crucial step prior to installation. A UXO strategy and risk assessment should be conducted on a project to define the risks and mitigations. (i.e., for trenching operations, insurance providers could possibly stipulate that a channel equal to +/- 20m of the center line of the installation to the anticipated trench depth plus 1m is UXO free or reduced to the ALARP level.)

Further guidance on cable burial is provided in the following document:

- BSEE TAP-671-Offshore Electrical Cable Burial for Wind Farms: State of the Art; Standards and Guidance; Acceptable Burial Depths and Separation Distances; and Sand Wave Effects
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.7
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.4
- CIGRE TB 610, Offshore generation cable connections - Section 6.3.6

9.8.2 Non-burial protection

Additional protection systems are available in the market and used depending on the project specific conditions and particularly in case of any crossing with other systems (see paragraph 9.8.3 below). availability of materials, cost and time to implement should also be considered

Different solutions are available on the market for protection, including but not limited to:

- Mattress
- Rock bag
- Rock berm
- Grout bag
- Articulated pipe

Different project specific conditions could favor a specific method, due to the area, or nature thereof.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.3.6.2, Section 6.3.6.3
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.7.3
- CIGRE TB 623, Recommendations for mechanical testing of submarine cables – Section 3.4

9.8.3 Infrastructure crossings

There already exists a large amount of infrastructure in the ocean, namely telecommunication cables, pipes, and power cables. With each asset it is understood that if there is a need to cross an existing asset, then a legal agreement is required. This legal agreement can take months to form as potential hazards and mitigations are established. Normal best practice for crossings is discussed in ICPC documentation. It should be noted that electrical (e.g., induction), mechanical Thermal implication and earthing (e.g., corrosion) issues are the norm for concern; however, proper engineering between the parties on all previous offshore projects has shown that a technical solution is always possible.

Please see the following references:

- CIGRE TB 610, Offshore generation cable connections - Section 6.2 and Section 6.3.3.
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.7.4

9.9 As-built survey

The contents of the as-laid documentation should be agreed between the parties at an early stage – already in the tender process.

Following the completion of cable installation operations, as-laid documentation should be provided. The data collected during the work and related surveys, including for example the as-buried and the as-built rock berm surveys, should be processed and edited for final presentation in the as-built documentation.

Please see the following references:

- CIGRE TB 610 Offshore generation cable connections - Section 6.6.2.
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.8

9.9.1 Survey Requirements

Specific survey requirements should be also discussed and agreed between the parties in due time and in line with the contractual obligations and project specific requirements.

Please see the following references:

- CIGRE TB 610 Offshore generation cable connections - Section 6.6.2
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.8.2

9.9.2 Inspection

A post-installation survey may be done to assure the cable is lying properly on the seabed and/or adequately buried. An as-built survey may be useful if the cable must be repaired or retrieved, another cable laid over or near it, or construction work done around it. The following techniques may be used to locate or observe the cable:

- Cable locating (toning, electromagnetic field detection, metal detector)
- Side scan
- Precision multibeam bathymetry
- Video or still photography via diver or ROV

9.10 After installation Inspection and Testing

Post installation testing (sometimes referred to as commission testing) is after the cable system is complete as defined by the contract between the parties. After installation inspection and testing may be done by multiple parties to satisfy contract obligation or permit requirements. The party may do a post installation testing at the completion of the cable system installation to allow fulfillment of contractual obligations. The other parties may perform post installation inspection and testing on the electrical system of the project to prove that the system is functioning correctly after being tied to the point of interconnection (i.e., the grid). The following subsections discuss what tests and inspections are typically done for a complete system.

9.10.1 Post - Inspection

A post-installation survey may be done to assure the cable is laying properly on the seabed and/or adequately buried. An as-built survey may be useful if the cable must be repaired or retrieved, another cable laid over or near it, or construction work done around it. The following techniques may be used to locate or observe the cable:

- Cable locating (toning, electromagnetic field detection, metal detector)
- Side scan
- Precision multibeam bathymetry
- Video or still photography via diver or ROV

Before a cable system is considered ready for operation or put into service, it should be visually inspected and tested. Inspection and testing activities may include the following:

a) Visual inspection: May include routing and fixing in offshore units and termination (mechanical, electrical) of the cable in accordance with the specification. This also applies after modifications and alterations.
b) Non-electrical tests: May include an OTDR test after installation, provided that the power cable contains optical fibers or is bundled with a fiber optic cable. The number of fibers to be tested should be agreed.
c) Electrical tests: Should include a high voltage test after termination. The combination of tests to use for a particular subsea cable system should be specified and the responsible parties should agree.
d) TDR testing of the power cores to compare to the fingerprint of the cable at the factor to the as laid cable.

Please see the following references:

- CIGRE TB 610 Offshore generation cable connections- Section 7.2 and Section 7.3
- DNVGL-RP-0360 – Subsea power cables in shallow water - Section 6.9.2

9.10.2 Electrical Tests

Tests on new installations are carried out when the installation of the cable system has been completed to verify the overall cable system condition prior to operation. The following electrical tests are available to ensure the cable has been installed without damage (the tests are not listed in any particular order):

- DC voltage test of the over sheath
- AC voltage withstand test of the over sheath

Please see the following reference for detail explanation of the testing methods:

CIGRE TB 773 - Fault location on land and submarine links (AC & DC)

9.10.2.1 DC Voltage Test of the Over Sheath

The voltage level and duration specified in Clause 5 of IEC 60229 should be applied between each metal sheath or metal screen and the ground unless the jacket is semi-conductive at which point the test is not applicable.

9.10.2.2 AC Voltage Withstand Test of the Insulation

Considering the importance of quality control of the cable system after installation it is recommended to carry out an AC voltage withstand test of the insulation. There are several factors in deciding on the method of testing to be used:

- The extent of further testing needed of the cable system including terminations after installation versus the risk of damaging the cable, switchgear, and accessories
- Space requirements and location of testing equipment, i.e., whether testing equipment is located onshore or on an offshore platform
- Availability of test equipment
- Timescales for testing and how it fits within the project delivery timeline
- Length of cables, voltage level, and total capacitance of cables to be tested have an impact on testing

The most up to date after installation AC insulation voltage withstand tests called out in the referenced cable standards are listed in items a), b), and c). Other methods of AC Voltage acceptance testing, such as item d), are available, however before implementation, their use should be agreed upon between the cable manufacture, purchaser and the parties. These test methods may be referenced directly by the cable standards in the future as these standards are revised. Historically the soak test (c.) is the most used test and usually the easiest to implement.

a) Series Resonant Test: test for a given time between 15 to 60 minutes, depending on the referenced cable standard, with AC voltage according to Table 4 column 10 of IEC 60840, Table 4, column 11 of IEC 62067 or Section 13.3 of IEC 63026 with a frequency between 20 Hz to 300 Hz applied between the conductor and the metal screen/sheath when testing to IEC 62067 or IEC 60840 and between 10 Hz to 500 Hz when testing to IEC 63026. In the case of very long lengths the minimum frequency may be reduced to 10 Hz subject to agreement between parties when testing to IEC 62067 or IEC 60840.
b) VLF Test: test for 15 min with the VLF voltage value of 3 U_0 at a frequency of at least 0.1 Hz applied between the conductor and the metal screen/sheath for cables with $U_m \leq 36$kV per IEC 63026.
c) Soak Test: test for 24 hours with the rated voltage U_0 of the system.
d) Damped AC Test: test for a given number of excitations of 50 or more with damped AC with a voltage according to IEEE400.4 and a frequency between 10 Hz to 500 Hz should be applied between the conductor and the metal screen/sheath.

Note: Per CIGRE TB 490, section 6.2, tests with damped AC voltage are generally combined with a PD measurement. This method is considered not to be suitable as a withstand voltage test and is more relevant for underground cables as the lengths are relatively short. Furthermore, PD measurements are performed primarily on accessories. Systems for damped AC voltage are so far not applicable for long submarine cables due to the high cable capacitance.

The standards that can be referenced for these other test methods include IEC 60060-3, IEC 60270, IEEE 400, IEEE 400.2, IEEE 400.3, or IEEE 400.4. A Partial Discharge test under AC voltage may be carried out by agreement between the parties during the AC voltage withstand test of the insulation. This may also be accompanied by a power factor or tangent delta measurement. The test procedure, voltage(s), test durations and pass/fail criteria for any tests should be agreed upon prior to testing between the parties.

Please see reference for additional information related to these test methods:

CIGRE TB 841 After Laying Tests on AC and DC Cable Systems with New Technologies

9.10.3 Time Domain Reflectometer

A “Finger-Print” of the cable taken with TDR equipment may be useful in locating faults in the future. The TDR usually identifies the location of splices in the cable for future reference points. It also helps estimate cable length or impulse propagation velocity. In three-core cables the estimated length may be longer than the actual distance to a splice or fault due to the twisting of the cable cores. The lay length of the cores should be considered when estimating the cable length to aid in more accurate results.

A TDR measurement should be performed for engineering information.

The propagation of the pulses used during TDR measurements is dependent upon resistance, capacitance, and inductance of the cable. As all electrical signals travel to consume a minimum of energy, the pulse propagates where the inductance/resistance is its lowest. Submarine power cables have a metal screen and the pulses do not propagate outside the screen since the inductance (and impedance) would increase considerably. Hence the pulse is not affected by the coiling on a turntable or after installation.

See CIGRE TB 490 -Section 11.2

9.10.4 Optical Time Domain Reflectometry

In case optical fibers are present in the cable, a “Finger-Print” of the optical cables taken with OTDR equipment may be useful in locating faults in the future. The OTDR should identify where fiber splices are located along the cable. It also helps estimate the cable length. However, due to the laying of the fiberoptic in the overall cable assembly the total length of the applied fiber optics may be greater than the actual length of the insulated cable. The lay length and overlength in fiber tube in the fiber cable should be considered if the results are being used to estimate the cable length to aid in more accurate results.

See CIGRE TB 610 - Offshore Generation Cable Connectors

10 OPERATIONS, MAINTENANCE, AND INTEGRITY MANAGEMENT

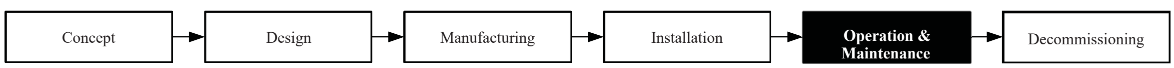
10.1 Asset Management and System Risk Awareness

See CIGRE TB 610 - Offshore Generation Cable Connectors

See CIGRE TB 825 Maintenance of HV Cable Systems

10.1.1 Operations and In-Service Inspections Section

Consideration of O&M begins during conceptual design, while the execution phase starts when construction activities have been concluded and the cable begins service. It's phase ends with decommissioning of the cable as shown on the figure below.



Milestones in the lifecycle of an Offshore wind farm

10.1.1.1 Operation and maintenance phase in a cable project lifecycle

This section provides requirements for the safe and reliable operation of a subsea power cable system during its service life with focus on management of cable integrity.

The operation phase of a power cable starts after the cable systems are successfully commissioned. This effectively means that the cable systems have been verified to be able to fulfill all project requirements either with relevant tests, inspections, or documentation. Such requirements comprise:

- Functional requirements - related to transmission capacity, voltage withstand capability and current rating. Cable systems are designed and tested such that they fulfill these requirements during the lifetime of the cable system without much maintenance. An exception is the cable current rating (transmission capacity), which is dependent on the cable burial depth and burial soil type. If these change, the cable current rating will be affected.
- Safety requirements - cable systems must be safe for people and environment. As such, it must be ensured that normal and special operating situations do not lead to unsafe situations. This may require monitoring and maintenance of the cable earthing systems.

- Reliability requirements - cable systems must be reliably performing their services. For that reason, cables are often protected by burial, concrete mattresses, pipes, or other measures. Monitoring and maintenance may be required to ensure the protection remains in place and functional.
- Regulatory requirements - safety and reliability requirements may be requirements from regulatory bodies. Such requirements may be very specific and location / state dependent.

In principle, most types of power cables and accessories are maintenance free for the duration of their lifetime. This especially holds for power cable systems with extruded insulation which are mostly used in offshore systems. However, the cable environment can change with time and can lead to situations which need to be avoided. A maintenance action therefore might be required to reinstate the cable environment to its designed environment.

Monitoring the condition of a submarine power cable is sometimes applied to offshore projects. Condition monitoring could comprise of fiber optic monitoring techniques such as distributed temperature sensing, distributed strain sensing, and/or distributed vibration sensing, but other monitoring techniques are also available on the market. Additionally, it is possible the connect in real time distributed vibration sensing with marine automatic identification systems to identify which ship anchor snagged a power cable. Also, cable fault localization is increasingly possible with fiber optic techniques. The primary goal of these condition monitoring techniques is to learn trends in the cable behavior caused by changes in the cable environment. An example is that temperatures can increase as a result of an increasing burial depth of the cable in the seabed. Another example is that vortex induced vibrations may occur in a submarine cable freely hanging in water as a result of a water current. Monitoring techniques are being developed to detect changes in the cable itself. (e.g., as a result of a PD activity or a heating connector in a joint).

10.2 Monitoring, Testing and Inspections

In addition to general inspection of subsea equipment systems, more intensive inspections should be specified for critical areas, as defined during the design process, such as areas of previous damage or repair and areas known to have higher frequency of degradation. At a minimum, the following subsea equipment should be included in any general inspection:

- Risers/J-tubes and attachments to the sub-structure
- Electrical IACs within field with particular attention to cables crossing other infrastructure
- Electrical Export cables with particular attention to cables crossing other infrastructure
- Connectors, junction boxes, grounding cables and fiber optic cables associated equipment See CIGRE TB 797.

- The cable inspections can confirm that buried cables remain at their installed depth beneath the sea floor. See CIGRE TB 610 - section 8.2.

10.2.1 Electrical Condition Monitoring Offline

Refer to section 9.10.2.2 of this document.

10.3 Fault Location

When cable breakdown occurs during operation, the operation will be stopped unless special configurations exist, and it is approved by the safety protocol set forth for the project. The cable system must be repaired before operation can be restored. The process in between comprises:

- To identify the fault type
- To pre-locate the fault, estimating the distance to the fault
- To set up a repair operation
- To pinpoint the fault location
- To repair the cable system

Techniques to pre-locate and pinpoint fault locations are extensively discussed in a recent work of CIGRE TB 773.

It is known that offshore repair operations can be costly and time consuming; therefore, emergency planning in case of a cable repair is a recommendable action. In emergency planning, topics to be considered are:

- Cable System Records
- Permits
- Preparatory Works

These topics are discussed in further detail in the following subsections.

10.3.1 Cable system records

Information on the cable systems should be readily available and up to date, comprising as laid information of the full cable route, all cable design and cable system design details, distances, commissioning test results, cable system fingerprints, and more.

10.3.2 Permits

Often, permits may be required to perform the repair works related to surveying of the cable route, diving activities, licenses for marine operations, etc.. Obtaining permits may be time consuming and should be prepared in advance as much as possible. Advanced establishment of emergency agreements for permission to mobilize is advisable to reduce repair and outage times. Be aware that these advanced agreements could involve the interconnection to other grid systems.

10.3.3 Preparatory works

Offshore cable repair requires the need of a dedicated recovery and repair vessel able to retrieve the cable from the sea floor, to hold the dedicated spare cable for the specific project, to hold the dedicated cable joints and to be equipped with jointing room for the specific project and a crew able to retrieve, repair and test the cable without any problem. Securing a vessel, the spare parts and correctly instructed personnel can be a time-consuming process and should be prepared in advance as much as possible.

Survey results and operational data of a cable should be reviewed for indications of problems. Measurement systems such as power quality and distributed temperature sensing may provide useful information on the operational history and overload conditions that could cause failure, see Section 10.2. Confirmation of the cable route is an important risk mitigation, discussed in Section 9.9.

Except where the fault location is obvious, several methods should be employed to locate a fault in a cable. Often a combination of coarse and fine location methods is advisable. For coarse location of a fault, measurements from both ends of the cable should be performed, where feasible. On cables where the voltage shape is continuously monitored with exact time stamps, the fault location may be inferred from the fault recordings at both cable ends.

Cable fault location techniques, their requirements, limitations, and guidance on pinpointing the fault are provided in DNVGL-RP-0360, Section 7.5.3 Fault Location. See also CIGRE TB 773.

Records of fault locations should be kept for future use and analysis. Faults in submarine power cables can be extremely costly as repair time can be long and during the outage no energy can be transmitted. Though good statistics are not available to substantiate, cable failures in submarine power cables happen regularly. Multiple reports exist detailing (often European) experiences. Also, in 2019, a 2-year joint industry project was launched to (amongst others) identify the root cause of submarine cable failures and to mitigate these causes CIGRE TB 815.

To avoid high costs as much as possible, it is important to have emergency plans available detailing how to proceed in case of a cable failure.

10.4 Repair Planning and Contracting

Normal operation of submarine power cables should not require active intervention. Periodic inspection along the cable route should be carried out to detect any changes in the depth of buried cables—in particular, exposure as a result of scour, subsidence, sand waves, and so on—or mechanical damage to the cable. Cables may also be designed with integrated fiber optic sensors that can detect changes in burial depth, strain, or temperature along the cable. If a cable becomes exposed, reburial or additional protection may be needed. Initial cable characterization using a method such as OTDR can provide a basis for comparison if a fault occurs.

Advance preparation of a repair plan is strongly recommended. After a fault has occurred, repair planning becomes time critical and mistakes or omissions that compromise safety are more likely. Guidance for developing a repair plan can be found in CIGRE TB 773 (Fault location on land and submarine links (AC & DC)). The information in IEEE 1234 (Guide for Fault-Locating Techniques on Shielded Power Cable Systems) is similar, but its focus is primarily on power cables installed on land. Key elements of a repair plan include:

1. Obtaining spare parts and cable
2. Storing spare stock appropriately so that it achieves its expected shelf life and replacing it as needed
3. Identifying local contractors with expertise and equipment available for cable locating, fault locating, and cable repair
4. Establishing agreements with identified contractors to provide timely response and repair for any cable problem that may arise
5. Specifying a safe operating plan for repair operations.

All repairs should be carried out by qualified personnel in accordance with agreed specifications and procedures defined for the cable system.

If the damaged cable is of a short length only (e.g., IACs between WTGs), a complete replacement of the cable may be the most economical solution. This involves securing the cable at one end and recovering it from the seabed after (or during) partial or complete de-burial. Installation of a new cable follows the steps of cable laying and burial (see Section 9.5.1).

If the cable damage is near a termination point, then a repair requiring only one inline joint may be feasible. In this case, the cable section between the termination point and damaged location is cut out and a new section is jointed in. After laydown of the inline joint, the cable is laid and pulled to the termination point as a second end pull operation.

If a cable repair is needed further away from either cable end and assuming that the cable and the fault have been located with sufficient accuracy (see Section 10.3), a repair sequence typically involves the following steps described in more details in CIGRE TB 680 - Implementation of long AC HV and EHV cable systems:

- de-burial of the cable along a section of sufficient length which is to be recovered
- cutting of the cable at the seabed (e.g., by ROV)
- recovery of first cable end and attaching a buoy to the second end
- removal of impaired part from the first cable end, jointing of spare cable section to first end
- laydown of first joint (as inline joint)
- recovery of second cable end, removal of impaired part, jointing with spare cable end
- laydown of second joint (typically as an omega repair bight; joint deployed first, then the quadrant with the repair bight crown)
- protection of laid cable, e.g., by burial or rockplacement.

Operational limiting conditions with regard to the sea-state, current and vessel movements should be established. Guidance on limiting meteorological and oceanographic (met ocean) criteria is available in API RP 2MOP/ISO 19901-6 Marine operations. The level of uncertainty in weather forecast should be considered, and the repair location should be verified prior to start of operations.

A survey should be performed to establish that the location is free of obstructions and that the seabed conditions will allow the repair work to be performed as specified. Further guidance on de-risking cable repair work is provided in DNVGL-RP-0360, Section 7.6 Repair work and DNVGL-ST-0359 Section 6.4.2 Repair work and execution.

Guidance on work required to maintain minimum cable protection and rectify free spans is provided in DNVGL-RP-0360, Section 7.4 Remedial work.

After completion of the repair, a survey of the cable on both sides of the repair area, and over a length sufficient to ensure that no damage has occurred, should be performed, see Section 9.9As-built survey.

All repairs should be inspected and electrically tested by experienced and qualified personnel in accordance with agreed procedures. Testing personnel, equipment, methods, and acceptance criteria should be agreed upon in accordance with Section 9.10. After installation inspection and testing

All intervention and repair works should be documented.

No existing standards or guidance have been identified concerning contracting.

10.5 Preservation and Storage

For submarine export cables, they usually need to be delivered in long and continuous lengths (to avoid offshore joints), from several tens of kilometers to more than 100 km. In this case, turntables are used for storage prior to transportation. Turntables are also used for intermediate storage (for instance prior to armoring) due to the long lengths to be stored. Consequently, HV submarine cable factories are usually equipped with several large turntables with loading capacity in the range of 10 000 tons, in order to store very long cables.

For IACs, depending on the logistic plan for installation and the installation vessel to be used, the lengths can be stored on drums or turntables. For exact length delivery such as in single turbine to turbine lengths, the limited length allows storage on drums. This exact length delivery should preferably be metallic drums, designed for sea transportation.

For delivery in complete or aggregated length, where the cable is cut and sealed offshore during installation operations, turntable storage is preferred

If the cable is coil-able, it is possible to store the cable by coiling in a static tank. In this case, a sufficient coiling height and coiling diameter should be considered to avoid bird caging of the armor due to the twist induced in each turn of the coil as described in CIGRE TB 623.

Picture: Turntable used for storage in a HV submarine cable factory

Preservation conditions, such as temperature range for storage, sun exposure, etc. should be stated by the cable manufacturer for the storage.

Due to transport and handling limitations, land cables are usually stored on drums, which are then used for the transport and installation. Lengths up to a few kilometers can be stored on drums. For long term storage, metallic drums should be preferred to wooden drums to avoid deterioration.

10.6 Spares Management

Submarine cable systems are very much designed and manufactured for each project individually and are therefore not easily interchangeable. If spare parts for a specific submarine cable are not available, are too small a length, or are beyond their conservation date, significant delays may be expected for the manufacturing or obtaining of these spare parts from elsewhere. Note that the problems can be compounded due to expired components of spare parts or unforeseen additional cable requirements due to incorrect fault locating.

10.6.1 Cable

Spare cables should generally be stored according to the conditions specified in section 10.5; however, in specific circumstances longer term storage of spare cable on or in the seabed ("wet storage") may be allowable. When planning wet storage, the risk of damage by a third party should be considered, with burial being a potential mitigation measure. Cables may also get damaged during recovery. Cables should be pre-rigged for retrieval.

If a cable route includes multiple cross sections, to a certain extent, a spare cable with a larger cross section size can be used to replace a cable with a smaller cross section. There is no required need to have a spare cable for each cross section provided the rigid repair joints can accommodate the cross-section changes. Additionally, double armored spare can be used for single armor cables.

10.6.2 Accessories

Spare repair parts and material such as jointing kits should be stored suitably protected to prevent deterioration or damage. Where applicable, expiration dates should be clearly marked on the parts and material. Systems should be put in place to ensure that components are replaced prior to the stated expiration dates provided by the manufacturer. As cable system projects age, accessories originally supplied with the project may no longer be available from the vendor and a suitable qualified replacement accessory should be obtained.

10.7 Warranty Management

See Chapter 4 in CIGRE TB 773 for warranty and insurance details.

11 DECOMMISSIONING

A decommissioning plan should be developed and approved as required by applicable regulations and should detail which components will be completely removed and which can be left in place. In addition, it should specify the safe working environmental conditions for each decommissioning activity and the order in which the activities will be conducted. Additional information on considerations in decommissioning planning are provided in DNVGL-ST-0359 Section 7 Decommissioning. General guidance on safe marine operations during decommissioning is available in DNVGL-RP-N102 Marine operations during removal of offshore installations.

Considerations should be made of the impact on the environment by removing the cables to determine if it would be better to abandon the cables in place over removal of the cables.

Logistically, cable removal can be started as soon as the turbines are de-energized and disconnected, working in parallel with the turbine and foundation removal operations. If the cables are to be left in place, the cable ends should be cut at each turbine. There will likely be either one, two or three cable ends at each turbine, and potentially work will be required at the transition to shore.

If the cables are to be fully removed, similar techniques to those used for cable installation are used. The method depends on soil type. One option is a combined jet plow, either towed or self-propelled and operated from the cable vessel. The jet plow loosens the soil and allows the cable to be pulled out by winches.

If the approved decommissioning plan requires removal of only specific lengths of cable, such as those that are insufficiently buried or susceptible to future exposure, then the lengths can be removed as above. The plan might specify that some cable lengths can be left in place if already protected by rock. A WROV could cut the ends close to or beneath the seabed and securely bury the end to avoid it being exposed in future. The short cut ends would be retrieved.

Where a future use of the cable is anticipated, decommissioning should be planned, conducted, and documented in such a way that degradation mechanisms are reduced, and the cable can be re-commissioned and put into service again. If the cables are to be recycled, it is not necessary to avoid cable damage during removal.

12 DOCUMENTATION/DATA MANAGEMENT REQUIREMENTS

The operating company should implement a management system that includes a process or procedure to maintain asset-related documents and records. The process should include a means to assure that documents and records can be identified, retained and are accessible. Documents should be periodically reviewed and revised as necessary, current versions made available. Obsolete documents should be removed or retained for legal use.

Note that some of the data that is generated may not be able to be viewed except on specific software platforms. Also, note that the amount of data could be up to or greater than 10 gigabytes and could require outside data storage resources to facilitate data management and transfer to concerned parties.

Records of a cable system withdrawn from service should be available and should include, but not be limited to:

- Details of out-of-service cable on land including route maps, the depth of burial and its location relative to surface features
- Details of out-of-service cables offshore, including navigation charts showing the cable route.

Appendix A: Standards Directly Referenced in this Recommended Practice

18 CFR 157	18 CFR Part 157 (APPLICATIONS FOR CERTIFICATES OF PUBLIC CONVENIENCE AND NECESSITY), FERC, BOEM,
30 CFR 585	Guidelines for Providing Archaeological and Historic Property Information Pursuant to 30 CFR 585
30 CFR 585	Guidelines for Providing Geophysical, Geotechnical and Geohazard Information Pursuant to 30 CFR 585
30 CFR 585	U.S. Title 30 of the Code of Federal Regulations (CFR), Part 585 "RENEWABLE ENERGY AND ALTERNATE USES OF EXISTING FACILITIES ON THE OUTER CONTINENTAL SHELF"
30 CFR 585.645	30 CFR 585.645- What must I include in my GAP?
30 CFR 585.626	30 CFR 585.626-What must I include in my COP?
ANSI C84.1	ANSI C84.1 Electric Power Systems And Equipment - Voltage Ratings (60 Hertz)
API	API specification for subsea umbilicals
API RP 2MOP	API RP 2MOP Marine Operations
ASCE Manual of Practice No. 108	ASCE Manual of Practice No. 108 Pipeline Installation by Horizontal Directional Drilling
ASCE Manual of Practice No. 115	ASCE Manual of Practice No. 115 Pipe Ramming

ASCE/CI 36	ASCE/CI 36, Standard Design and Construction Guidelines for Micro tunneling
ASTM D1141-98	ASTM D1141-98 Standard Practice For The Preparation Of Substitute Ocean Water
ASTM F1962	ASTM F1962 Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipeline or Conduit Under Obstacles, Including River Crossings
BSEE TAP Report Number 671	BSEE TAP Report Number 671, Offshore Electrical Cable Burial for Wind Farms: State of the Art, Standards and Guidance & Acceptable Burial Depths, Separation Distances and Sand Wave Effect.
Carbon Trust, 2015 CBRA	Carbon Trust, 2015, Application Guide for the Specification of the Depth of Lowering using the CBRA Methodology
Carbon Trust, 2015 CTC835	Cable Burial Risk Assessment Methodology, Guidance for the Preparation of Cable Burial *Depth of Lowering* Specification, Carbon Trust, CTC835, February 2015
CENELEC EN 50180	CENELEC EN 50180 Bushings above 1 kV up to 52 kV and from 250 A to 3,15 kA for liquid filled transformers
CENELEC EN 50181	CENELEC EN 50181 Plug-in type bushings above 1 kV up to 52 kV and from 250 A to 2,50 kA for equipment other than liquid filled transformers
CIGRE Session 2016 B1-303	CIGRE Session 2016 B1-303 Systematic Description of Dynamic Load for Cables for Offshore Wind Farms. Method and Experience
CIGRE TB 303	CIGRE TB 303 REVISION OF QUALIFICATION PROCEDURES FOR HV AND EHV AC EXTRUDED UNDERGROUND CABLE SYSTEMS

CIGRE TB 490	CIGRE TB 490 Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage above 30 (36) to 500 (550) kV
CIGRE TB 610	CIGRE TB 610, Offshore generation cable connections
CIGRE TB 623	CIGRE TB 623 Recommendations for mechanical testing of submarine cables
CIGRE TB 669	CIGRE TB 669 Mechanical Forces in Large Cross Section Cable Systems
CIGRE TB 680	CIGRE TB 680 - Implementation of long AC HV and EHV cable systems:
CIGRE TB 722	CIGRE TB 722 Recommendations for Additional Testing for Submarine Cables from 6 kV up to 60 kV
CIGRE TB 770	CIGRE TB 770 Trenchless technologies
CIGRE TB 773	CIGRE TB 773 - Fault location on land and submarine links (AC & DC)
CIGRE TB 797	CIGRE TB 797 Sheath Bonding Systems of AC Transmission Cables - Design, Testing, and Maintenance
CIGRE TB 815	CIGRE TB 815 Update of service experience of HV underground and submarine cable systems
CIGRE TB 825	CIGRE TB 825 Maintenance of HV Cable Systems
CIGRE TB 841	CIGRE TB 841 After Laying Tests on AC and DC Cable Systems with New Technologies
CIGRE TB 852	CIGRE TB 852 Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to and including 800 kV

CIGRE WG B1.56	CIGRE WG B1.56 verification of cable current ratings April 2019
CIGRE WG B1.67	CIGRE WG B1.67 Loading Patterns on Windfarm Array and Export Cables
CIGRE WG B1.70	CIGRE WG B1.70 Recommendations for the use and the testing of optical fibers in submarine cable systems
CZMA	National Coastal Zone Management Program CZMA of 1972
DNGVL-RP-F107	DNGVL-RP-F107 Risk Assessment of Pipeline Protection
DNVGL-RP-0360	DNVGL-RP-0360 - Subsea Power Cables in Shallow Water, 2016
DNVGL-RP-C205	DNVGL-RP-C205 Environmental Conditions and Environmental Loads
DNVGL-RP-F109	DNVGL-RP-F109 ON-BOTTOM STABILITY DESIGN OF SUBMARINE PIPELINES
DNVGL-RP-N102	DNVGL-RP-N102 Marine operations during removal of offshore installations
DNVGL-ST-0126	DNVGL-ST-0126 Support structures for wind turbines
DNVGL-ST-0359	DNVGL-ST-0359, Subsea Power Cables for Wind Power Plants, DNV GL, June 2016.
DNVGL-ST-C501.	DNVGL-ST-C501 Composite components
DNVGL-ST-N001	DNVGL-ST-N001 Marine operations and marine warranty
EPRI	EPRI Underground Transmission System Reference Book
FERC 2000	FERC Order No. 2000 [Docket No. RM99-2-000; Order No. 2000] Regional Transmission Organizations (Issued December 20, 1999)

FERC 888	FERC Order No. 888 (Issued April 24, 1996) Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities
FERC 889	FERC Order No. 889 (Issued November 25, 1997) Open Access Same-Time Information System and Standards of Conduct
ICEA S-108-720	ICEA S-108-720 Standard for Extruded Insulation Power Cables Rated above 46 through 500 kV AC
ICEA S-94-649	ICEA S-94-649 Standard for Concentric Neutral Cables Rated 5 Through 46 kV
ICEA S-97-682	ICEA S-97-682 Standard for Utility Shielded Power Cables Rated 5 Through 46 kV
ICEA-S-93-639	ICEA-S-93-639 5-46 kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy
ICPC Recommendation 13	ICPC Recommendation 13, The Proximity of Offshore Renewable Wind Energy Installations and Submarine Cable Infrastructure in National Waters
ICPC Recommendation No. 3	ICPC Recommendation No. 3, Telecommunications Cable and Oil Pipeline/Power Cables Crosssing Criteria
ICPC Recommendation No.1	ICPC Recommendation No.1: Recovery of Out of Service Cables
ICPC Recommendation No.13	ICPC Recommendation No.13, Issue: 2B Issue Date: 26 November 2013, or latest revision
ICPC Recommendation No.2:	ICPC Recommendation No.2: Cable Routing and Reporting Criteria
ICPC Recommendation No.3	ICPC Recommendation No.3: Telecommunications Cable and Oil Pipeline / Power Cables Crossing Criteria

ICPC Recommendation No.4	ICPC Recommendation No.4: Co-ordination Procedures for Repair Operations Near In Service Cable Systems
ICPC Recommendation No.7	ICPC Recommendation No.7: Offshore Civil Engineering Work in the Vicinity of Active Submarine Cable Systems
ICPC Recommendation No.9	ICPC Recommendation, Recommendation No.9, Minimum Technical Requirements for a Desktop Study (also known as a Cable Route Study)
ICPC Recommendations 2	ICPC Recommendations 2 - Cable Routing and Reporting Criteria
ICPC Recommendations 9	ICPC Recommendations 9 - Minimum Technical Requirements for a Desktop Study
IEC 60038	IEC 60038 IEC standard voltages
IEC 60060-3	IEC 60060-3 High-voltage test techniques - Part 3: Definitions and requirements for on-site testing
IEC 60183	IEC 60183 Guidance for the selection of high-voltage A.C. cable systems
IEC 60228	IEC 60228 Conductors of insulated cables
IEC 60229	IEC 60229 Electric cables - Tests on extruded oversheaths with a special protective function
IEC 60270	IEC 60270 High-voltage test techniques - Partial discharge measurements
IEC 60287-1-1	IEC 60287-1-1 Electric cables - Calculation of the current rating - Part 1-1:Current rating equations (100 % load factor) and calculation of losses - General
IEC 60287-1-2	IEC 60287-1-2 Electric cables - Calculation of the current rating - Part 1: Current rating equations (100 % load factor) and calculations

	of losses - Section 2: Sheath eddy current loss factors for two circuits in flat formation
IEC 60287-1-3	IEC 60287-1-3 Electric cables - Calculation of the current rating - Part 1-3: Current rating equations (100 % load factor) and calculation of losses - Current sharing between parallel single-core cables and calculation of circulating current losses
IEC 60287-2-1	IEC 60287-2-1 Electric cables - Calculation of the current rating - Part 2-1: Thermal resistance - Calculation of thermal resistance
IEC 60287-2-2	IEC 60287-2-2 Electric cables - Calculation of the current rating - Part 2: Thermal resistance - Section 2: A method for calculating reduction factors for groups of cables in free air, protected from solar radiation
IEC 60287-2-3	IEC 60287-2-3 Electric cables - Calculation of the current rating - Part 2-3: Thermal resistance - Cables installed in ventilated tunnels
IEC 60287-3-1	IEC 60287-3-1 Electric cables - Calculation of the current rating - Part 3-1: Operating conditions - Site reference conditions
IEC 60287-3-2	IEC 60287-3-2 Electric cables - Calculation of the current rating - Part 3-2: Sections on operating conditions - Economic optimization of power cable size
IEC 60287-3-3	IEC 60287-3-3 Electric cables - Calculation of the current rating - Part 3-3: Sections on operating conditions - Cables crossing external heat sources
IEC 60840	IEC 60840 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
IEC 60853-1	IEC 60853-1 Calculation of the cyclic and emergency current rating of cables. Part 1: Cyclic rating factor for cables up to and including 18/30(36) kV

IEC 60853-2	IEC 60853-2 Calculation of the cyclic and emergency current rating of cables. Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages
IEC 60853-3	IEC 60853-3 Calculation of the cyclic and emergency current rating of cables - Part 3: Cyclic rating factor for cables of all voltages, with partial drying of the soil
IEC 61757-2-2.	IEC 61757-2-2 Fibre optic sensors - Part 2-2: Temperature measurement - Distributed sensing
IEC 61914	IEC 61914 Cable cleats for electrical installations
IEC 62067	IEC 62067 Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) - Test methods and requirements
IEC 62095	IEC TR 62095 Electric cables - Calculations for current ratings - Finite element method
IEC 62271-209	IEC 62271-209 High-voltage switchgear and controlgear - Part 209: Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV - Fluid-filled and extruded insulation cables - Fluid-filled and dry-type cable-terminations
IEC 63026	IEC 63026 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
IEC Electropedia	IEC Electropedia International Electrotechnical Vocabulary (IEV) or Electropedia, which is available for free. Anyone can consult it
IEEE 100	IEEE 100 “The Authoritative Dictionary of IEEE Standards Terms”

IEEE 1127	IEEE 1127 Guide for Design, Construction and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility
IEEE 1234	IEEE 1234 (Guide for Fault-Locating Techniques on Shielded Power Cable Systems)
IEEE 1300	IEEE 1300 IEEE Guide for Cable Connections for Gas-Insulated Substations
IEEE 400	IEEE 400 Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above
IEEE 400.1	IEEE 400.1 Guide for Field Testing of Laminated Dielectric, Shielded AC Power Cable Systems Rated 5 kV to 500 kV Using High Voltage Direct Current (HVDC)
IEEE 400.2	IEEE 400.2 Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)(less than 1 Hz)
IEEE 400.3	IEEE 400.3 Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment
IEEE 400.4	IEEE 400.4 Guide for Field Testing of Shielded Power Cable Systems Rated 5 kV and Above with Damped Alternating Current (DAC) Voltage
IEEE 575	IEEE 575 Guide for Bonding Shields and Sheaths of Single-Conductor Power Cables Rated 5 kV through 500 kV.
IHO No 44	International Hydrographic Organization IHO Standards for Hydrographic Surveys, Special Publication N° 44, 2008.
ISO 13628-5	ISO 13628-5, Petroleum and natural gas industries - Design and operation of subsea production systems—Part 5: Subsea umbilical’s, Section 15.15: Pipeline crossing

ISO 19901-6	ISO 19901-6 Petroleum and natural gas industries — Specific requirements for offshore structures — Part 6: Marine operations
ISO 19902	ISO 19902 Petroleum and natural gas industries — Fixed steel offshore structures
ISO 9001	ISO 9001 Quality management systems — Requirements
ISSMGE	Geotechnical & Geophysical Investigations for Offshore and Nearshore Developments, ISSMGE, September 2005. International Society for Soil Mechanics and Geotechnical issmge.org
NASTT	NASTT Horizontal Directional Drilling (HDD) Good Practices Guidelines. North American Society For Trenchless Technology
NORSOK Standard G-001	Marine Soil Investigations, NORSOK Standard G-001, October 2004, Standards Norway
OCRP 2012	*AWEA Offshore Compliance Recommended Practice (OCRP) 2012. AWEA has changed name to ACP*
OCRP 1 WG1	OCRP 1 - Working Group 1 - ACP Offshore Compliance Recommended Practices (OCRP) Edition 2
OCRP 2 WG2	OCRP 2 - Working Group 2 - ACP U.S. Floating Wind Systems Recommended Practices
OCRP 3 WG3	OCRP 3 - Working Group 3 - ACP U.S. Offshore Wind Metocean Conditions Characterization Recommended Practices
OCRP 4 WG4	OCRP 4 - Working Group 4 - ACP U.S. Recommended Practices for Geotechnical and Geophysical Investigations and Design
OCRP 5 WG5	OCRP 5 - Working Group 5 - ACP Recommended Practices for Submarine Cables

OSIG	OSIG, Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments, May 2014. Society for Underwater Technology, sut.org
The Crown Estate	The Crown Estate, Export transmission cables for offshore renewable installations – Principles of cable routing and spacing.
UN UNCLOS	United Nations Law of the Sea Convention (1982) ("UNCLOS")
US DOI-BSEE E14PC00005	Offshore Wind Submarine Cable Spacing Guidance", Contract # E14PC00005, US DOI – BSEE, December 2014
US OCS	US Outer Continental Shelf (OCS) Renewable Energy Program. https://www.boem.gov/renewable-energy
BOEM Geophysical, Geotechnical, Geohazard, And Archaeological Guidelines	See reference: www.boem.gov/newsroom/notes-stakeholders/updated-geophysical-geotechnical-geohazard-and-archaeological
ICPC Recommendations 1 through 14	ICPC Recommendations 1 through 14 (http://www.iscpc.org/).
BOEM Survey Guidelines For Renewable Energy Development	BOEM Survey Guidelines ACP U.S. Recommended Practices for Geotechnical and Geophysical Investigations and Design BOEM Survey Guidelines can be found here: https://www.boem.gov/renewable-energy/survey-guidelines-renewable-energy-development

Appendix B: Additional Standards Related to Submarine Cable Systems

BSEETA&R 627, Assess/develop inspection methodologies for offshore wind turbine facilities
BSEETA&R 633, Wind farm/turbine accidents and the applicability to risks to personnel and property on the OCS, and design standards to ensure structural safety/reliability/survivability of offshore wind farms on the OCS
BSEETA&R 650, Offshore wind turbine inspection refinements
BSEETA&R 651, Evaluate the Effect of Turbine Period of Vibration Requirements on Structural Design Parameters
BSEETA&R 656, Seabed Scour Considerations
BSEETA&R670, Design Standards for Offshore Wind Farms
CIGRE (2000a), *“Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage 30 (36) to 150 (170) kV.”Electra (189:1)*.
CIGRE (2000b), *“Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage 30 to 170kV.” Electra (189:2).*
CIGRE (2003), *“Testing DC Extruded Cable Systems for Power Transmission up to 250kV.” Electra (206:4).*
CIGRE (2005), “Recommendations for Tests of Power Transmission DC Cables for a Rated Voltage up to 800kV.” Electra (218:3).
CIGRE (2012). “High-Voltage On-Site Testing with Partial Discharge Measurement”, Technical Brochure 502.
CIGRE (Conference Internationale des Grandes Reseaux Electriques) (1997), *“Recommendations for Mechanical Tests on Submarine Cables. “Electra (171:3)*.

Renewable UK and Crown Estate (2011). "Guidance Notes for the Utilization of Vessels Engaged as Guard/Escort Vessels During Cable Operations," Revision C, December 16.
GR-20CORE Issue 4, 2013, Generic Requirements for Optical Fiber and Optical Fiber Cable
ANSI/ICEA S-87-640, Standard for Optical Fiber Outside Plant Communications Cable
IEC 60502-1, Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV)—Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)
IEC 60794-1-11, Outdoor Cables - Product specification for duct, directly buried, and lashed aerial single mode fiber telecommunications cables. IEC 60793 series – Optical fibers
IEC 60794-3-10, Outdoor Cables - Family specification for duct, directly buried, or lashed area optical telecommunications cables
IEEE 1142, Guide for the Selection, Testing, Application, and Installation of Cables Having Radial-Moisture Barriers and/or Longitudinal Water Blocking
Reference 1: D. Chatzipetros ; J. A. Pilgrim, Induced Losses in Non-Magnetically Armoured HVAC Windfarm Export Cables, 2018 IEEE International Conference on High Voltage Engineering and Application (ICHVE)
Reference 2: Yuki Matsumoto, et. al, 3D FEM analysis of armour loss in three core submarine cables, Jicable 2019
Reference 3. Marius HATLO, Espen OLSEN, Ronny STØLAN, Accurate analytic formula for calculation of losses in three-core submarine cables, Jicable 2015 E2.5
Reference: Eric Dorison, George J. Anders and Frederic Lesur, Ampacity Calculations for Deeply Installed Cables, EEE TRANSACTIONS ON POWER DELIVERY, VOL. 25, NO. 2, APRIL 2010
Reference: George J. Anders, RATING OF CABLES ON RISER POLES, IN TRAYS, IN TUNNELS AND SHAFTS - A REVIEW, IEEE Transactions on Power Delivery, Vol. 11, No. 1, January 1996
Worzyk, T. (2009). Submarine Power Cables: Design, Installation, Repair, Environmental Aspects. ICEA No.S-57-401/NEMA Standards Publication No.WC2. Heidelberg, Germany: Springer-Verlag.
UKCPC. (2010). “Doc No. 4.1.5 v6.” United Kingdom Cable Protection Committee.

Appendix C: Standards Organizations Related to this Recommended Practice

ADCI	Association of Diving Contractors International	https://www.adc-int.org
AEIC	Association of Edison Illuminating Companies	https://aeic.org
ANSI/ICEA	American National Standards Institute	https://www.ansi.org
API	American Petroleum Inst	
ASME/ANSI	American Soc Mechanical Engineers	
AWEA	American Wind Energy Association	https://www.awea.org/
BOEM	Bureau of Ocean Energy Management	https://www.boem.gov/
BOEM	BOEM and the Bureau of Safety and Environmental Enforcement (BSEE)officially replaced the Bureau of Ocean Energy Management, Regulation ,and Enforcement (BOEMRE) on October 1, 2011. References to BOEMRE, or its Mineral Management Service predecessor,	
Book	Submarine Power Cables: Design, Installation, Repair, Environmental Aspects Textbook by Thomas Worzyk	*www.springer.com*
BSEETA&R	Bureau of Safety and Environmental Enforcement (BSEE) Technology Assessment & Research (TA&R)	https://www.bsee.gov/newsrooom/fact-sheets/technology-assessment-program
BSUH	Bundesamtfür Seeschiffahrt und Hydrographie - Federal Maritime and Hydrographic Agency of Germany	www.bsh.de/en/index.jsp

CE	Conformité Européenne	
CIGRE	International Council on Large Electric Systems- Conseil International des Grands Réseaux Électriques, abbreviated CIGRÉ	www.cigre.org
Ciria	construction industry research and information association. London UK	
CSA	Canadian Standards Association	
CUL	Canadian UL	
DNV GL	DNV GL is an international accredited registrar and classification society -Det Norske Veritas (Norway) and Germanischer Lloyd (Germany).	dnvgl.com
ELECTRA	Electra : CIGRE's Bilingual Bimonthly Journal for Power System Professionals	
ENA	Energy Networks Association-Energy Networks Association (ENA) represents the ‘wires and pipes’ transmission and distribution network operators for gas and electricity in the UK and Ireland.	www.energynetworks.org
EPRI	The Electric Power Research Institute, or EPRI, conducts research, development, and demonstration projects to benefit the public in the United States and internationally.	epri.com
FM	FM Global - Factory Mutual	www.fmglobal.com
ICEA	Insulated Cable Engineers Association	http://www.icea.net/
ICPC	International Cable Protection Committee Ltd - UK	https://www.iscpc.org
IEC	International Electrotechnical Commission	www.iec.ch
IEEE	Institute of Electrical and Electronics Engineers	www.ieee.org

IMCA	International Marine Contractors Association - London UK	https://www.imca-int.com
ISO	International Organization for Standardization - The International Organization for Standardization is an international standard-setting body composed of representatives from various national standards organizations.	iso.org
JICABLE	JICABLE objective is, through the organisation of meetings and publications, to train, inform, valorise and ensure the development of science and technology in the field of insulated power cables, their installation, operation and associated technologies. it was formed by Société de l'électricité, de l'électronique et des technologies de l'information et de la communication	jicable.org jicable@see.asso.fr
NEC - NFPA70	NFPA 70®, National Electrical Code® (NEC®), sets the foundation for electrical safety in residential, commercial, and industrial occupancies.	nfpa.org
NEMA	National Electrical Manufacturers Association	NEMA.ORG
NESC	National Electrical Safety Code - IEEE/ANSI	
NFPA	The National Fire Protection Association (NFPA) is a global nonprofit organization, established in 1896, devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards.	https://www.nfpa.org/
UKCPC	United Kingdom Cable Protection Committee	
UL	UL is a global safety consulting and certification company headquartered in Northbrook, Illinois. Formally referred to as Underwriters Laboratories	ul.com
	'IMCA HSSE' series (including former SEL or S&L documents): SEL =Safety, Environment & Legislation	