Offshore Wind Submarine Cable Spacing Guidance

Contract # E14PC00005

United States Department of Interior
Bureau of Safety and Environmental Enforcement

December 2014, For Public Use

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The authors gratefully acknowledge permission of the Crown Estate to base parts of this report on their study "Principles of Cable Routing and Spacing (2012)", Reference ID 8 in this report

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Abbreviations

AC	Alternating Current
AIS	Automatic Identification System
ALARP	As Low As Reasonably Practicable
AWEA	American Wind Energy Association
BOEM	Bureau of Ocean Energy Management
BPI	Burial Protection Index
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
CIGRÉ	Conseil International des Grands Réseaux Électriques
COP	Construction and Operations Plan
CVA	Certification and Verification Authority
CZMA	Coastal Zone Management Act
DC	Direct Current
DGPS	Differential Global Positioning System
DP	Dynamic Positioning
DTS	Desk Top Study
EMF	Electromagnetic Field
ERO	Electric Reliability Organization
FDR	Facility Design Report
FERC	Federal Energy Regulatory Commission
FIR	Fabrication and Installation Report
GPS	Global Positioning System
HDD	Horizontal Directional Drilling
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICEA	Insulated Cable Engineers Association
ICPC	International Cable Protection Committee
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
NASCA	North American Submarine Cable Association
NERC	North American Electric Reliability Corporation
NGO	Non-governmental Organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
ROV	Remotely Operated Vehicle
ROW	Right Of Way
SAP	Site Assessment Plan
SCUK	Subsea Cables United Kingdom
SQSS	Security and Quality of Supply Standard
TA&R	Technology Assessment and Research Program
TAP	Technology Assessment Program
UKHO	United Kingdom Hydrographic Office

UNCLOS	United Nations Convention on the Law of the Sea
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
UXO	Unexploded Ordnance
VTS	Vessel Traffic Service

1. Introduction

1.1. Background to research study

Until recently, developments in offshore electricity generation and the need for long distance power transmission, planned spacing between power cables has largely been a function of economic requirements and grid connection constraints (both key factors in routing decisions). Historically, subsea power transmission links were limited to a few miles in length linking islands to the mainland grid or between points on the mainland where a submarine route across a bay or estuary was economically and technically viable. Such short links are typically concentrated at the most convenient point for connection to the transmission grid and, where strong enough or reinforced, additional cables could be concentrated into that area to meet growing demand.

The distance constraints on subsea HVAC (high voltage alternating current) transmission are now being widened with new technology but still remain limited in efficiency to about 100 km. Developments in HVDC (high voltage direct current) transmission have allowed for longer transmission systems. As the development of offshore transmission of electricity increases, the need for consideration of effective and efficient use of space and routing becomes increasingly important. This is not only to take account of other users of the ocean, the seabed or offshore resources, but also for the security and integrity of the installed assets and of electricity supply.

This report seeks to identify the factors determining spacing between power transmission cables. While the focus of the report is the development of the offshore wind power transmission around the United States, the findings and conclusions may be considered relevant when determining spacing between cables for other purposes and indeed, between cables and other seabed assets.

In compiling this report it has been identified that there is not an extensive U.S. library of pertinent studies, guidance, data or information and it has been necessary to draw on the experience of other nation states and industries where relevant experience can inform the study.

The objective of this report is to provide a technical reference informing the regulator and developers and provide best practice guidance in respect of cable spacing for the developing offshore wind industry in U.S. waters.

1.2. Objectives

While offshore wind remains a nascent industry in the U.S., significant development throughout the UK and Europe has resulted in a major expansion of the offshore transmission network required to link offshore generation with the onshore grid. In Europe, the increased need for electrical transmission infrastructure has led to developers and transmission operators competing for cable routes and access in increasingly congested coastal and offshore areas. This has increased the chance of conflicts arising between the developers themselves and with other entities with commercial and conservation interest in the seabed. Delays in permitting have been experienced and arguably unnecessary demands imposed upon developers by regulators and other stakeholders.

These experiences highlight the need to fully understand the spatial requirements associated with offshore wind submarine cable systems in order to appropriately plan for the growth of the U.S. industry. In order to help inform future offshore wind development activities in the U.S., this report analyses spacing requirements for offshore transmission and collection (inter-array) system cables. It is anticipated that the contents of this guidance report will form a point of reference that will assist BSEE in reviewing cable route proposals for offshore wind projects and inform developers on factors to be considered. Furthermore, it is our expectation that the report will also serve to inform and educate the wider investment, insurance, and other regulatory communities, providing a valuable resource regarding the factors that influence spacing between offshore transmission cables for offshore wind farm developments.

The ultimate goal of this effort is to develop a clear and concise report that will offer valuable guidance to BSEE, as well as the broader industry:

- To provide BSEE with general criteria for assessing the cable spacing proposals from developers based upon best industry practice;
- To develop guidance that may be utilized by BSEE, and more broadly by the U.S. offshore wind industry, during the design, development and review of offshore wind collection and transmission systems.

1.3. Scope of study

The research undertaken for this initiative seeks to build upon earlier studies that have been conducted under the Technology Assessment and Research Program, particularly TA&R 671 – Offshore Electrical Cable Burial for Offshore Wind Farms on the Outer Continental Shelf, and other relevant research and reports (e.g., http://bsee.gov/research-and-training/operationalsafety-and-engineering.aspx).

In referencing previous research, the relevant content generated for the current effort is generally consistent and any discrepancies or differences identified are explained. Aside from work that has been carried out under the TA&R program, this study has benefitted from the extensive research that has previously been carried out for The Crown Estate in the UK, and many European projects, as well as from several U.S. projects from related industry sectors.

While the study addresses all areas of the marine transmission cable route from the point of generation to the shore landing point, the resulting guidance focuses specifically on the following four areas:

- Array cables;
- Funneling around offshore substation platforms (OSPs);
- Export transmission cables; and
- Funneling at approaches to landfall positions and coastal congestion.

The study considers four important issues that have a defining influence on the routing and spacing of transmission cables in order to optimize lifetime integrity of the cables, considering the needs of other seabed users:

- Route design and development;
- Cable spacing to meet system reliability and grid stability requirements;
- Installation/operation and maintenance of existing and future transmission cables; and
- The effects of electromagnetic fields on navigation and local ecology.

Best practice guidelines from industry bodies such as the International Cable Protection Committee (ICPC), Subsea Cables UK (SCUK) and the North American Submarine Cable Association (NASCA) have been used as a basis for the study together with the results from the 2012 Cable Spacing Study undertaken for UK Crown Estate. The principles of cable route development already adopted by the offshore cable industry have also been considered in terms of best practice drawing on the authors' considerable experience in planning, installing, operating and maintaining subsea cables. Drawing upon broad industry experience, various equipment, vessel types, engineering options and methodologies are discussed.

The following principles have also been taken into account in this study:

- Importance of effective and early constraints mapping, including engineering constraints; and
- Avoidance of pinch points, congestion and bottlenecks.

Within the constraints of the study, the U.S. state and federal regulatory and consenting regimes have been reviewed in context, including initiatives on spatial planning, cable corridors or cable protection zones. The interests of statutory, other industry (e.g., asset owners and fishing) and conservation bodies have also been assessed, and recommended principles of engagement with these bodies have been provided.

The report is structured to address the following questions which developers will need to consider when planning cable routes:

- What are the issues and risks?
- Why do they need to address the issues and risks?
- Who is involved (i.e. key stakeholders)?
- How will the developer deal with the issues and risks?
- When do they need to do it?

1.4. Structure of report

In addition to this section, Section 1 – Introduction, the report is structured as follows:

Section 2 – Subsea cables associated with offshore wind farms
Section 3 – Summary of existing studies and guidance
Section 4 – Review of impact of regulatory regime and stakeholder engagement on cable spacing
Section 5 – Factors affecting cable spacing, including:

- Overview of factors to be considered and associated actions necessary to define cable spacing
- Route design and development
- Strategic routing for safeguarding transmission integrity
- Spacing to allow for effective installation, operation and maintenance
- Spacing to minimize risk
- Effects of EMF on navigation and ecology and implications for cable spacing
- Funneling at coastal and offshore connection points

Section 6 – Conclusions and recommendations

2. Subsea cables associated with offshore wind farms

Offshore wind farm cable elements include those that bring energy from individual turbines (array cables) within the wind farm area to an Offshore Substation Platform – OSP- (one or more depending on the extent of the wind farm) generally within the wind farm boundary limits and then from the OSP to landfall (export cables – also known as transmission cables). Wind farms close to shore (typically up to 60 to 100 km) may use HVAC in the export cables; for greater distances HVDC may be the most economical transfer method. If an HVDC transmission system is used, then in addition to OSPs there may be one or more AC/DC Convertor Offshore Platforms within the wind farm development area, necessitating additional inter-platform transmission AC cabling.

The number of export cables from an offshore wind farm to the shore is usually a function of principal electrical design needs (e.g., output from the wind farm) while considering aspects of system security, redundancy, diversity in case of cable failure (e.g., from external sources such as ships' anchor dragging), third party asset proximity (e.g., other cables and pipelines), other seabed users (e.g., fishing, dredging activity), environmental or regulatory issues. HVDC export cables in a bi-pole configuration may be bundled together or laid separately from the OSP/Convertor Platform to the shore. There is, therefore, no unique configuration in cable and therefore cable spacing design.

For the purpose of this study it is assumed that a number of array cables funnel (converge) into an OSP; export cables funnel out of the OSP (i.e., diverge); export cables run shoreward before finally funneling (converging) to a landing point on the coastline (landfall funneling). An example layout is given in Figure 1.

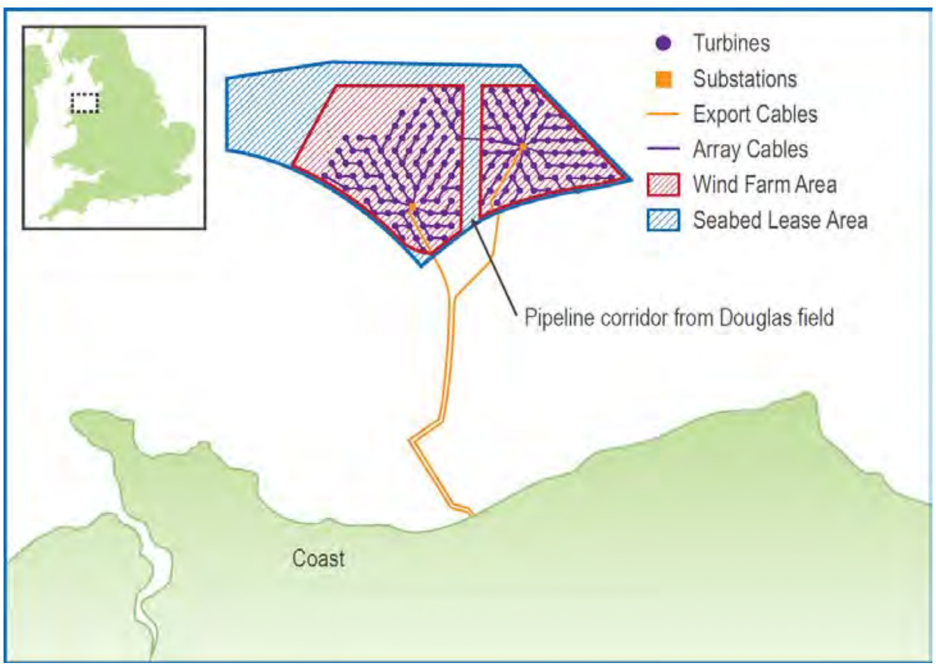

Figure 1. Example of Offshore Wind Warm Layout and Export Cable System – Gwynt-Y-Mor, UK (reproduced courtesy of Gwynt y Môr Offshore Wind Farm Limited)

Spacing of cables within the turbine array (array cables) is often more constrained than with export cables; the objective is to link turbines optimally and with the shortest (economical) route to the OSP. Within a wind farm development there may be pre-existing assets (e.g., third party cables or pipelines) that have to be avoided or crossed. Other stakeholder interaction may therefore be warranted. Generally, to date, wind turbines among existing offshore developments are spaced approximately 600 - 1000 meters apart; this places some constraints on access for installation and maintenance/ repair vessels. Therefore, cable spacing needs to consider ongoing access to structures for operations and maintenance.

Additionally, the routing of array cables and / or the ground conditions on site will impact burial tool selection. Greater separation between turbines may be anticipated in the future as technology develops and wind turbines become larger.

The subsequent sections provide an explanation of the factors that affect cable spacing. These factors take into consideration the issues and risks to overcome and approaches to managing and mitigating those risks, stakeholder involvement, and how these factors fit into project schedules.

Principal reference sources for this study are listed numerically and relate to the numbered references in Section 3 of this report unless specified differently. This report, while taking the salient points from these references, does not attempt to reproduce all of the content of these reference documents.

3. Summary of existing studies and guidance

A search for relevant studies and guidance has been conducted and those that have or contain relevant material are listed in the table below. The table also provides a summary of that document's scope and key recommendations/ requirements or relevance in relation to cable spacing.

Note that the sequence of references listed below does not imply a hierarchy of importance or relevance. However, references 1 – 10 are the most important in consideration of cable spacing; representing international law (references 1 – 3) and international and national guidance (references 4 – 10) respectively. it could be considered that legal references provide an over arching framework of requirements and that international and national guidance documents developed by governments and trade associations provide the core information that should be considered in defining cable spacing.

Reference ID. No	Study/Guidance document	Scope	Key Recommendations/ Requirements/ Relevance
1	**UNCLOS (1982)** **United Nations Convention on Law of the Sea** **Articles 21, 51, 56, 58, 60, 79, 112, 113, 114, 115, 145, 192, 206** **(http://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm)**	Establishes through the Convention the legal basis for adoption by a Nation State of commonality of regulation internationally Defines the limits of territorial and international waters, etc., including exclusive economic zones Articles provided specifically on topics in the context of submarine cables Establishes legal basis for matters beyond a nation States jurisdiction	Should be considered in conjunction with relevant federal and state legislation Provides that all states are entitled to lay cables on the Continental Shelf (outside territorial seas). Establishes responsibility to protect cables and liability of parties damaging cables Various articles addressing the rights of a Nation State to lay and operate submarine cables and the rights of passage of ships engaged in laying or repairing submarine cables Provides also for prosecution for negligent or willful damage to power cables, and compensation in respect of sacrifice to protect submarine cables Requires the protection of the marine environment and establishes a duty upon a nation State to do so and to monitor and assess(although EMF and cables not specifically mentioned)
2	**Geneva Convention on the Continental Shelf (1958) – Relevant Provisions** **(http://cil.nus.edu.sg/rp/il/pdf/1958%20Convention%20on%20the%20Continental%20Shelf-pdf.pdf)**	The Convention on the Continental Shelf was an international treaty created to codify the rules of international law relating to continental shelves. The treaty, after entering into force on 10 June 1964, established the rights of a sovereign state over the continental shelf surrounding it, if there be any. The treaty was one of three agreed upon at the first United Nations Convention on the Law of the Sea (UNCLOS I). It has since been superseded by a new agreement reached in 1982 at UNCLOS III (see above Reference 1) The treaty dealt with seven topics: the regime governing the superjacent waters and airspace; laying or maintenance of submarine cables or pipelines; the regime governing navigation, fishing, scientific research and the coastal state's competence in these areas; delimitation; and tunneling	Article 4: The coastal state may not impede the laying or maintenance of submarine cables or pipelines on the continental shelf Article 5-2: The coastal state is entitled to construct and maintain or operate on the continental shelf installations and other devices necessary for its exploration and the exploitation of its natural resources, and to establish safety zones around such installations and devices and to take in those zones measures necessary for their protection Article 5-3: The safety zones referred to in 5-2 may extend to a distance of 500 m around the installations and other devices which have been erected, measured from each point of their outer edge. Ships of all nationalities must respect these safety zones

Reference ID. No	Study/Guidance document	Scope	Key Recommendations/ Requirements/ Relevance
3	***Geneva Convention on the High Seas (1958) – Relevant Provisions*** ***(http://www.gc.noaa.gov/documents/8_1_1958_high_seas.pdf)***	The Convention on the High Seas is an international treaty created to codify the rules of international law relating to the high seas, otherwise known as international waters. The treaty was one of four treaties created at the United Nations Conference on the Law of the Sea (UNCLOS I). As such, whilst useful as background information the UNCLOS 1982 document at the top of this table (Reference 1) should be referenced as primary noting that most of the same content is included in both documents	Article 26-1: All states shall be entitled to lay submarine cables and pipelines on the bed of the high seas Article 26-2: Subject to its right to take reasonable measures for the exploration of the continental shelf and the exploitation of its natural resources, the coastal state may not impede the laying or maintenance of such cables or pipelines Article 26-3: When laying such cables or pipelines, the state in question shall pay due regard to cables or pipelines already in position on the seabed. In particular, possibilities of repairing existing cables or pipelines shall not be prejudiced
4	**ICPC Recommendation No.2 (Issue 10B, Nov 2012)** **Recommended Routing and Reporting Criteria for Cables in Proximity to Others** **International Cable Protection Committee** **(http://www.iscpc.org/)**	Cable Routing and Reporting Criteria for Cables in Proximity to others	Describes viable separation of parallel cables as 3 x water depth (Sect 2.9) but does not amplify that this is determined on the basis of telecoms repair ships using traditional deep water cable recovery methods (towed grapnel) Refers only to separation for telecoms cables not power cables Developments in technology and shallow water techniques make ICPC Guidance No. 13 more relevant to the subject of this study
5	**ICPC Recommendation No.9 (Issue 4B, March 2012)** **Minimum Technical Requirements for a Desktop Study (DTS)** **International Cable Protection Committee** **(http://www.iscpc.org/)**	Details industry standard minimum requirements for an evidentiary based study to identify and confirm potential constraints, threats, sensitivities, stakeholders and third party interests along or proximate to a potential cable route	Provides a reference for best practice for cable routing, the proper assessment and analysis of the specific factors affecting the route(s) under consideration and due regard to other stakeholders, their rights and potential impact upon the development under consideration May also be referred to as a route engineering study, or similar, and may be compiled in several parts over a period of time or as a single exercise Provides the initial basis for design, route development work for survey and geophysical/ geotechnical interpretation, permit application, environmental assessment and engineering design and planning; industry standard principles relevant to determining cable spacing

Reference ID. No	Study/Guidance document	Scope	Key Recommendations/ Requirements/ Relevance
6	**ICPC Recommendation No.13 (Issue 2A, November 2013)** **The Proximity of Offshore Renewable Wind Energy Installations and Submarine Cable Infrastructure in National Waters** **International Cable Protection Committee** **(http://www.iscpc.org/)**	Recommended practice for the management of interaction between proximate assets	Suggests an approach including early dialogue with stakeholders to determine site specific proximity limits based on a risk assessment of the circumstances and conditions of the situation Drawn up by ICPC following publication of SCUK Guidance No.6 providing a more international perspective Provides guidance on a risk assessed approach to proximate issues
7	**Proximity Study** **Submarine Cables and Offshore Renewable Energy Installations** **The Crown Estate, (UK) 2012** **(http://www.thecrownestate.co.uk/media/5708/submarine-cables-and-offshore-renewable-energy-installations-proximity-study.pdf)**	Evidential basis for the development of guidance for proximate issues between offshore wind farms and submarine cables in close proximity (primarily telecommunications cables) The substantive basis for SCUK Guidance No.6 and ICPC Recommendation No.13	Primary recommendation is that each situation is risk assessed on a case-by-case basis The report offers base case examples for defining minimum approach distances of repair vessels to offshore wind farms and describes a control process to be followed with regard to DP rating of the vessels involved Considers engineering requirements for repair and spatial planning The appendices provide useful reference for issues relevant to spacing and proximity, of practical and legislative use UK-centric but combined with ICPC Recommendation No 13 gives a detailed and more international perspective
8	**Principles of Cable Routing and Spacing** **The Crown Estate (UK) 2012** **(http://www.thecrownestate.co.uk/media/5642/principles_of_cable_routing_and_spacing.pdf)**	Spacing between export transmission cables for offshore renewable installations	Due to the considerable variation in local issues and circumstances, the spacing between cables should be considered on a <u>case-by-case</u> basis applying an appropriate site specific risk assessment Discusses the factors affecting cable spacing as route design/development; system security (SQSS); installation; maintenance, and the effects of EMF on navigation and the ecology (Principal source document for this study)

Reference ID. No	Study/Guidance document	Scope	Key Recommendations/ Requirements/ Relevance
9	**Guidelines for leasing of export cable routes/corridors** **The Crown Estate (UK) 2012** **(http://www.thecrownestate.co.uk/media/5518/guideline_for_leasing_of_export_cable_routes.pdf)**	Internal guidance for the agency responsible for the leasing of the UK seabed Reviews and assesses the factors affecting routing and spacing of transmission cables for offshore wind farm developments	The guideline outlines the process for cable route application, assessment and approval (or rejection) without frustrating the use of the seabed for others Appendix 1 Cable route project approval information may form useful basis of study. Draws on the "Principles of Cable Routing and Spacing" report (Crown Estate, 2012) UK-centric but relevant in principle
10	**SCUK Guidance No 6** **2012** **The Proximity of Offshore Renewable Energy Installations & Submarine Cable Infrastructure in UK waters** **(http://www.thecrownestate.co.uk/media/5658/proximity-of-offshore-renewable-energy-installations-submarine-cable-infrastructure-in-uk-waters-guideline.pdf)**	Guidance for Indicative Separation Distances Key factors determining proximity limits Stakeholder Consultation Processes for determining site specific proximity limits Proximity agreements	Establishing site specific proximity limits based on a case-by-case risk assessment and the principles of As Low as Reasonably Practical (ALARP). Recommendation for effective early Stakeholder interaction is emphasized Preceded ICPC Recommendation No 13, developed as industry guidance from The Crown Estate Proximity Study Similar to ICPC No 13 but specific to North West European waters and UK continental shelf particularly A document developed relating to interaction of Offshore Renewable Energy infrastructure and telecommunication cables in general but with direct relevance to HVAC and HVDC inter-array and export cable installation and maintenance/repair issues
11	**Offshore Electrical Cable Burial for Offshore Wind Farms on the OCS** **BSEE Technology Assessment Program (TAP) Project 671** **(Also known as TA&R project 671)** **December 2011 (release date)** **Report date November 2011** **(Bureau of Safety and Environmental Enforcement, USA. http://www.bsee.gov/Research-and-Training/Technology-Assessment-and-Research/Project-671)**	Written for Bureau of Ocean Energy Management. A general guide for the planning of offshore submarine cable projects, drawing on experience from U.S. oil & gas, telecoms and some European offshore wind projects. Sets out guidance on issues to be considered for route planning, cable burial protection, vertical cable separation and some elements of horizontal separation, and installation along with a review of regulatory framework. General observations about system configuration types pertaining to HVAC and HVDC transmission differences	Recommendations are valid but are not specific to cable spacing and do not reflect recent European experience that spacing of cables should be specified on a case by case basis Section 5.3.2 discusses aspects of 'suitable' minimum horizontal distances between paired cables (not bundled) – for repair purposes; conflicting figures but generally 2 x water depth or 50m minimum separation (may be less if there are engineering constraints). Also discusses due regard for 3rd party cables and assets Separation distances should also consider redundancy issues to mitigate multiple failures from an external source (e.g., anchor strike). Risk based analysis on a case-by-case basis recommended in this respect (200 yards minimum recommended for initial planning purposes) Risk analysis recommended to assess thermal issues when cables run close to pipelines Informs on issues to be considered for route planning and engineering. Useful background data for European OWF, EMF and Thermal effects

Reference ID. No	Study/Guidance document	Scope	Key Recommendations/ Requirements/ Relevance
12	**BOEM 30 CFR Part 585** **Bureau of Ocean Energy Management, USA** **(http://www.boem.gov/Code-of-Federal-Regulations/)**	Guidelines for providing geological, geophysical, hazards and archaeological information	Survey guidelines for early surveys prior to SAP (Site Assessment Plan) or COP (Construction and Operations Plan) application Informs on best practice for early stage surveys and provides relevant comment on investigations and data acquisition necessary to inform routing decisions and relevant to cable protection issues
13	**AWEA OCRP 2012** **AWEA Offshore Compliance Recommended Practices 2012** **American Wind Energy Association, USA** **(http://www.awea.org/Resources/contentlist.aspx?metadataid=56&startrow=11&endrow=20)**	Recommended practices for design, deployment, and operation of offshore wind turbines in the United States Initial planning activities which include site development, ecological issues, socio-economic issues and other leasing and permitting issues not covered	Sect.7.3.4 Addresses proposed guidelines for cable surveys and installation including BOEM 30 CFR 585 and ICPC Recommendation No.9 (Minimal technical requirements for a desktop study) Sect 10 Details current US Regulations and confirms no codes for spacing of cables Appendix A.6.3 'Offshore Transmission Grid or backbone' summarizes network types; Appendices in A.7.2. discuss aspects of offshore wind facility submarine cable installation, cable protection and cable burial AWEA is an accredited standards developer under the authority of the American National Standards Institute No specific guidance on cable separation recommendation within this document
14	**IEEE Std 1120 (2004)** **IEEE Guide for the Planning, Design, Installation, and Repair of Submarine Power Cable Systems** **The Institute of Electrical and Electronic Engineers, Inc. Published 2005.** **Sponsor: Insulated Conductors Committee of the IEEE Power Engineering Society** **(http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1425768&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F9761%2F30793%2F01425768)**	Guide for planning, design, installation and repair of submarine power cables	Section 5.1.4 Cable spacing: General comments only; stating that when multiple cables are installed the farther they are spaced apart the less likely more than one cable will be damaged by a single external cause. Cables are commonly spaced far enough apart to allow for a section to be cut out, a new section spliced in and then lowered to the seafloor. The greater the depth, the farther apart the cables should be laid The guide provides a list of factors to consider when planning, designing, permitting, installing, commissioning, and repairing submarine power cable systems
15	**DNV-OS-H101 Marine Operations (General) (Oct 2011)** **&**	Provides general requirements for planning, preparations and performance of marine operations	Considered in context the documents provide relevant reference for risk management strategy, planning and design Pertinent to spacing considerations when considering the engineering associated with design,

Reference ID. No	Study/Guidance document	Scope	Key Recommendations/ Requirements/ Relevance
	DNV-RP-H101 Marine Operations (Jan 2003) **(http://www.dnvgl.com/)**		development, installation, operations and maintenance of an offshore wind farm development
16	**DNV-RP-J301 (February 2014)** **Subsea Power Cables in Shallow Water Renewable Energy Applications** **(http://www.dnvgl.com/)**	This recommended practice provides guidance for all phases of the life cycle of subsea power cable projects, with a focus on shallow water renewable energy applications	Promotes a risk based approach whereby risks are reduced to acceptable levels. Provides internationally applicable guidance by defining minimum requirements which constitute industry 'best practice'. Serves as an important reference document between stakeholders such as developers, designers, manufacturers, purchasers, installers, owners, operators, certifiers, investors and insurers References the various ICPC documentation referred to above it is a comprehensive document feeding off ICPC and Crown Estate documentation in particular with respect to cable spacing Section 4.5.2 discusses parallel routing of power cables; section 4.5.3 proximity to existing infrastructure Optimum spacing of two or more power cables should be determined considering project internal and external factors (i.e., a risk-assessed case-by-case determination. Due consideration should be given to the potential repair of a cable and subsequent repair bights. Proximity to existing infrastructure (e.g., pipelines and other third party cables) should be carefully assessed with all stakeholders at an early stage of design
17	**National Grid and The Crown Estate (September 2011)** **Offshore Transmission Network Feasibility Study**	Assesses alternatives for the development of an offshore network (grid) in the UK. Options are radial, radial plus and integrated offshore network	Identifies a number of benefits in an integrated offshore transmission network: • savings (amounting to a total of £6.9 billion by 2030) in comparison to a radial design. • reduced land take and environmental impact • more flexible transmission network – improved operational and congestion management. Potential savings would be largely delivered through a reduction in the required assets to connect the offshore generation, notably the transmission cables. Coordinated design offshore would require a clear regulatory framework, delivered in a timely manner.
18	**Navigant Consulting Inc (Nov 2012) Offshore Wind Market and Economic Analysis for US Dept of Energy**	Provides a comprehensive assessment of the U.S. offshore wind market. Serves as a road map for removing entry barriers and increasing U.S. competitiveness in the offshore wind market.	Has useful background and guidance on the challenges for electrical infrastructure required to develop offshore wind in the U.S. and policy decisions required to support this. Examples of transmission policies that can be implemented in the short term with relatively little effort are to (a) designate offshore wind energy resources zones for targeted grid investments, (b) establish cost allocation and recovery mechanisms for transmission interconnections, and (c) promote utilization of existing transmission capacity reservations to integrate offshore wind.

Table 1. Review of studies and guidance

In August 2013, the North American Submarine Cable Association endorsed the adoption and application of the Subsea Cables United Kingdom Guideline No. 6, *The Proximity of Offshore Renewable Energy Installations & Submarine Cable Infrastructure in UK Waters* by the US regulatory agencies to all offshore renewable energy projects, including wind, tidal, and wave projects until such a time that specific guideline are developed by the industry. They have also adopted ICPC recommendations for use in the U.S.

3.1. Key findings drawn from literature review

It is apparent from the literature review undertaken that there is a good amount of guidance available that can inform decisions on cable spacing. **However there is no one size fits all solution or single "rule of thumb" in terms of defining cable spacing. Due to the considerable variation in local issues and circumstances, the spacing between cables should be considered on a case-by-case basis incorporating all relevant information (e.g., shipping and fishing data, ground conditions, installation and repair techniques) and taking into account site/route -specific risk assessment. Proper application of subject matter experts is also important, and due regard should be made to expert knowledge being fed into projects at the appropriate time.** Whilst some European administrations have taken a prescriptive approach to defining cable spacing requirements, burial requirements and specifying suitable corridors for cable routing, these prescriptive requirements have been challenged by developers to optimize cable routes and associated installation and maintenance costs through the use of proven engineering methods. This suggests that each project should be considered on a case-by-case basis with developers taking into account all of the factors that are discussed in this document in order to make decisions on suitable cable spacing appropriate to the particular circumstances.

It is clear from the review that established references for best practice exist to inform spatial planning and routing for subsea cables. Key topics covered in existing guidance that have a defining influence on the routing and spacing of offshore transmission cables are:

- Route design and development;
- Cable spacing to meet redundancy requirements;
- Installation/operation and maintenance of existing and future transmission cables; and
- The effects of electromagnetic fields on navigation and local ecology.

Early dialogue with stakeholders is recommended in much of the available guidance to determine site-specific proximity limits as appropriate.

In the U.S. marine environment, BOEM has authority over renewable energy installation on the outer continental shelf. As of this writing the authors are unaware of any guidance established by government agencies for offshore energy cables in the U.S. In the private sector, the American Wind Energy Association (AWEA) has developed the AWEA Offshore Compliance Recommended Practices (Reference ID 13). This document provides a wealth of information and references to other groups who have developed recommendations that may be relevant. In North American and some Latin American countries, the Insulated Cable Engineers Association (ICEA) writes standards for some power cables. The International Electrotechnical Commission (IEC) recommendations are used for other cables and in other regions. Standards developed by the Council on Large Electric Systems (Conseil International des Grands Réseaux Électriques - CIGRÉ) may have relevant material and recommendations – but these typically relate to matters of electrical design rather than cable routing as such.

It should be noted that with the recent upsurge in activity related to the construction of offshore wind farms worldwide, wind farm developers and transmission owners do not have extensive experience of offshore installation activities compared to, say, the telecoms or hydrocarbon sectors. While power cable installation has a strong history, major projects have been sporadic. In recent years, the volume of installation activity has risen sharply and companies have adopted best practice guidelines and recommendations from industry groups, such as ICPC, and applied these to their own projects. In Australia and across Europe, power cable owners are also joining industry-wide groups such as ICPC and Subsea Cables UK, to ensure that they continue to learn from and apply best practice to their projects.

4. Regulatory regime and stakeholder engagement

4.1. International Law

As noted in Section 3 above, UNCLOS and the Geneva Convention form the basis of most national regulatory regimes for subsea cables and include specific provisions in relation to subsea cables. However, there are no specific references to spacing of cables in either.

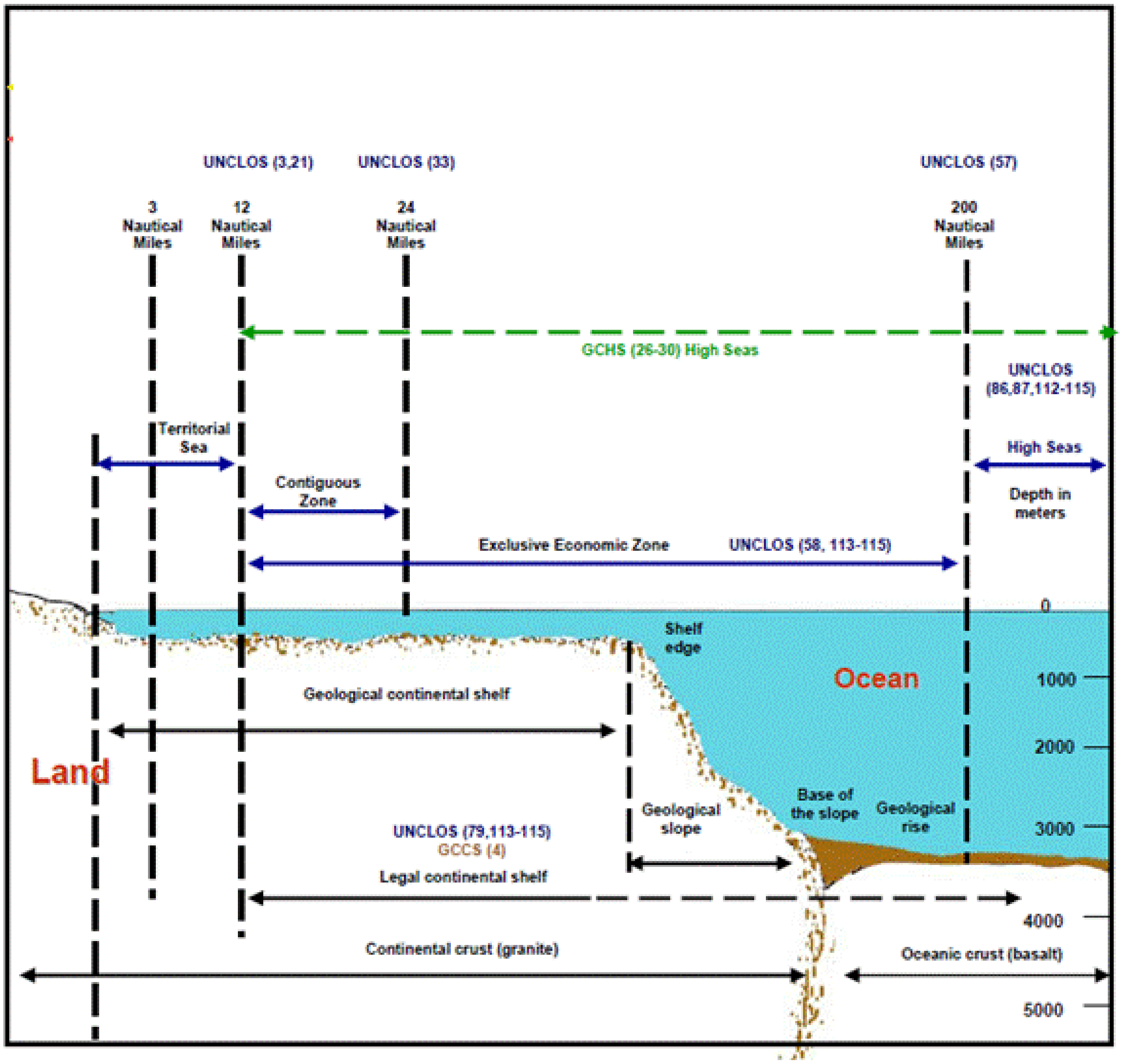

Figure 2. Summary of relevant legislation regarding use of the seabed (source: Squire, Sanders & Dempsey LLP)

4.2. US Regulatory Regime

There is currently limited regulatory guidance with regard to subsea cable spacing for offshore wind farms. A previous report funded by the BSEE, TA&R 671 *Offshore Electrical Cable Burial for Offshore Wind Farms on the Outer Continental Shelf*, identified the applicable regulations to be considered for cable system design and installation. BOEM, the U.S.

Army Corps of Engineers (USACE) and the United States Coast Guard (USCG) are the regulatory bodies with jurisdiction with regard to Offshore Renewable Energy Installations.

4.2.1. Federal Regulations

BOEM is the lead regulatory authority for leasing and licensing associated with offshore wind farm projects.

Regulations with regard to cable system design are included in 30 Code of Federal Regulations (CFR) 585 Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf (OCS) (formerly 30 CFR 285) as summarized below:

- 30 CFR 585.301: A Right of Way (ROW) grant includes the full length of the corridor on which a cable, pipeline or associated facility is located. It is 200 feet (61 meters) in width, centered on the cable or pipeline, unless safety and environmental factors during construction and maintenance of the associated cable or pipeline require a greater width and is limited to the area reasonably necessary.
- 30 CFR 585.658: Every effort must be taken to ensure that all cables and pipelines are constructed in a manner that minimizes deviations from the approved plan under the lease or grant.
- 30 CFR 585.701 (a) (4): This states that the Facility Design Report (FDR)[1] must provide specific details of the design of any facilities, including cables and pipelines that are identified in the Construction and Operations Plan (COP).
- 30 CFR 585.702 (a) (7): This states that the Fabrication and Installation Report must describe how the facilities will be fabricated and installed within the design criteria identified in the Facility Design Report and the approved COP. This includes the design of any cables, pipelines or facilities.
- 30 CFR 585.705: This states that a Certification and Verification Authority (CVA) must be used to review and certify the FDR and the Fabrication and Installation Report (FIR). This requirement may be waived if it can be demonstrated that the facility design conforms to a standard design that has been used successfully in a similar environment and the installation design conforms to accepted engineering practices.
- 30 CFR 585.816: If environmental or other conditions adversely affect a cable, pipeline or facility so as to endanger safety or the environment a plan of corrective action must be submitted within 30 days of discovery of the adverse effect, take remedial action as described in the corrective plan and submit a report to BOEM of the remedial action taken 30 days after completion.

The “Outer Continental Shelf Lands Act”, (BOEM, 1953) defines the OCS as all submerged lands lying seaward of state submerged lands and waters (as defined in the Submerged Lands Act, typically 3 nautical miles offshore) which are under U.S. jurisdiction and control to the seaward extent of Federal jurisdiction (typically 200 nautical miles).

The United States Army Corps of Engineers have responsibilities for regulating discharge of dredged material and work in, and affecting, navigable waters of the US (Reference ID 11) under Title 33, Code of Federal Regulations, Parts 320-330 and accordance with Section 10 of Rivers and Harbors Act of 1899 (33 U.S.C. 403), and Section 404 of the Clean Water Act 33 U.S.C 1344). 33 CFR 322.3 (b) states permits are required for the construction of artificial islands, installations and other devices on the seabed, which therefore includes any subsea cables.

Approval of the burial depth and separation distances is required from the nearest District Engineer of the USACE, who will specify depth requirements and any other pertinent conditions relevant to cable installation, operation and maintenance.

Sharples (Reference ID11) undertook a review of burial depths agreed with USACE in the TA&R 671 study and from this it can be assumed that:

[1] Under the regulations developers are required to submit various plans for approval by BOEM at various stages. The key plans are a site assessment plan (SAP), a construction and operation plan (COP), a General Activities Plan (GAP), and a Facility Design Report (FDR). The regulations are prescriptive in terms of the information, drawings, design information and data that should be presented in these documents.

- In an anchorage area or marine park: burial depths specified are likely to be around 15 ft.(5 m) below seabed
- Otherwise, the required burial depth may be as low as 3-6 ft (1-2 m).

In order to be enforceable, burial requirements must be specified with consideration of local conditions. For example, in areas of coral and other sensitive habitats, burial may not be preferred. Other means of protection may be more favorable for both the cable and the environment. On steep slopes or hard rock, burial may not be practical. Local activities and their potential effects on cables should also be considered. Much of the fishing gear presently in use does not penetrate the seabed deeply, but in limited areas, aggressive gear such as mechanized clam dredges warrant deeper cable burial.

No change in the role or responsibilities of the USCG has occurred since the publication of TA&R 617. The USCG has no specification or detailed remit with regard to cable spacing. However, the responsibilities of USCG are laid out in a Memorandum of Agreement between the BOEM and US Coast Guard. The USCG's areas of responsibility with regards to offshore wind farm projects are mainly related to the approval of project Navigation Safety Plans (in which cable installation, burial and spacing may be a consideration depending on the navigation issues in the specific area of interest) and Aids to Navigation.

The Coastal Zone Management Act (CZMA) (16 U.S.C. 1451 et seq.) requires federal agencies to ensure that permitted activities are consistent with coastal management programs that have been developed by individual states and approved by the National Oceanic and Atmospheric Administration (NOAA). The regulations covering this are presented in 15 CFR part 930, and the requirement is summarized in http://www.boem.gov/Coastal-Zone-Management-Act/. The consistency requirement gives states substantial influence and discretion in cable permitting, installation and maintenance. For example, a state with a broad continental shelf, containing many shallow-water resources of commercial value and environmental and cultural importance, could require lengthy, rigorous study and mitigation measures. A state with a narrow shelf and less focus on coastal natural resources and activities, placing a higher priority on the benefits of coastal development, might require a less rigorous process for consistency certification.

4.2.2. State Regulations

State permitting requirements for cable installations vary from state to state. This research is not intended to list all of the various permits for installation, but rather point out that there are no prescriptive state requirements for the spacing of cables offshore. Depths for cable burial may be mandated by the state, for example New Jersey has a minimum burial depth requirement in state waters of 5 ft (1.5m). Cable burial depths at landfalls are engineered per site with stakeholder input such as the utility, town or municipality. The consistency requirement mentioned above also gives states substantial influence and discretion in cable permitting, installation and maintenance.

4.3. Stakeholder interfaces

There are a number of stakeholders that can influence the routing, spacing and installation of cable assets. The table below outlines stakeholder groups, their broad areas of concern or interest and potential impacts upon cable spacing. It is important to note that federal agencies, state agencies, commercial fishermen, recreational fishermen, tribes, and NGO environmental groups often have very different interests and concerns with regards to subsea cables. For project purposes it is considered good practice to engage with each stakeholder organization on an individual basis to introduce the project and discuss their interests and concerns.

Stakeholder groups	Areas of concern/interest	Potential impacts on cable spacing
Federal and State Environmental Authorities Nongovernmental organizations (NGOs) focusing on nature conservation	Impacts upon the natural environment. Issues of concern that have been raised in relation to subsea power cables are the impacts on seabed habitats from cable installation and potential impacts of electric and magnetic fields upon electro-sensitive species.	Cable spacing may be impacted by the need to avoid a particularly sensitive seabed habitat (e.g., reef). EMF concerns are unlikely to impact upon cable spacing, except in cases where cable bundling is intended to have the magnetic fields of adjoining cables cancel each other (typically in water depths less than 100ft (30.5m)). This is discussed in more detail in Section 5 below.
Third party cable, pipe line, wind	Ensuring their asset is protected from harm and	May wish to dictate prescriptive requirements for separation

Stakeholder groups	Areas of concern/interest	Potential impacts on cable spacing
farm and oil and gas infrastructure owners	ensuring safe and effective access to their assets for operations, maintenance and repair activities.	distances from their assets or activities to prevent opportunities for commercial losses.
Federal (e.g., NOAA National Marine Fisheries Service, US Fish and Wildlife Service)	Impacts upon fish and fishing. Therefore, such organizations may raise concerns about impacts upon sensitive habitats for fish spawning and impacts upon electro-sensitive species.	Cable spacing may be impacted by the need to avoid a particularly sensitive seabed habitat. EMF concerns are unlikely to impact upon cable spacing, except in cases where cable bundling is intended to have the magnetic fields of adjoining cables cancel each other out (typically in water depths less than 100ft (30.5m)).
State fishery, environmental and historical preservation agencies	Preservation of the environment and resources with consideration of species and activities of local prominence. Interests of commercial and recreational fishermen, beachgoers, tourism, etc.	Avoidance of critical and sensitive habitats, prime recreational and commercial fishing grounds, avoidance of seasonal activities (beachgoing, intensive fishing periods, spawning periods and habitats, etc.). Avoidance of damage to historical and archaeological objects, monitoring of project installation and operation for damage to living and non-living objects of interest.
Tribes	Tribes have fishing rights in several states, the most prominent being Washington. There, about 20 tribes have treaty rights with the US government to take fish unencumbered in their Usual and Accustomed areas. These rights have been reinforced by several court decisions. In Washington, tribes generally have the right to take half the fishery resources deemed available for harvest. Fisheries are co-managed by the NMFS, Washington State, and Tribal authorities. Tribes may oppose any installations that could hinder access, or cause resource depletion, fishing gear damage or loss. Also preservation of cultural and archaeological sites, items and species of historic and cultural importance.	Avoidance of fishing grounds, adequate burial to prevent interference with fishing, assurance of compensation for damaged or lost fishing gear, timing of installation and maintenance to avoid intensive fishing seasons. Avoidance of sites with special cultural and archaeological significance.
Commercial fishermen	Access to fishing grounds and resources, conservation of species of commercial value, avoidance of damage or loss of fishing gear caused by project installation or operation, avoidance of interference especially during intensive fishing seasons.	Avoidance of fishing grounds, adequate burial to prevent interference with fishing, assurance of compensation for damaged or lost fishing gear, timing of installation and maintenance to avoid intensive fishing seasons, clear guidelines supporting the two industries' coexistence. Provision for ongoing access to traditional fishing grounds.
Recreational fishermen	Access to fishing grounds and resources, conservation of species of recreational interest, avoidance of damage or loss of fishing gear caused by project installation or operation, avoidance of interference especially during intensive fishing seasons.	Avoidance of fishing grounds (which may be different from commercial fishing grounds), adequate burial to prevent interference with fishing, avoidance of peak recreational fishing seasons.
NGO environmental interests	Conservation of species and habitats, avoidance of disturbance of spawning, mating, migration, with special concern for endangered, threatened or charismatic species.	Avoidance of critical habitats and seasons of special concern for particular species, monitoring for impacts, mitigation to protect sensitive resources.
Shipping and navigation authorities (e.g., USCG) and groups	Impacts upon shipping and navigation. Issues of concern tend to be associated with potential for anchor snagging and effects of electric and magnetic fields on compass deviation.	Risk of anchor snagging and compass deviation can impact on cable spacing, depending on nature of shipping and navigation activities and features (e.g., anchorage areas, traffic separations schemes, port approaches). Risk assessments are required to inform cable spacing and burial and potential relocation of anchorages. Early engagement with relevant authorities is recommended.
Recreational users	Impacts upon their activities. Issues of concern can include disruption to popular areas during installation works; effects of electric and magnetic fields on compass deviation and potential for anchor snagging.	Risk of anchor snagging and compass deviation can impact on cable spacing.
State and Town Regulatory	Ensuring cables remain buried and do not pose a	Not specific, but some local authorities may request particular

Stakeholder groups	Areas of concern/interest	Potential impacts on cable spacing
Authorities	hazard to human health.	spacings based on local factors.

Engagement with stakeholders is often most productive and effective if it is begun as early as possible in project planning.

The advantages of early engagement include:

- It can be more cost effective and time efficient to incorporate stakeholders' inputs before substantial time and investment have been spent on particular courses of action or design;
- It can be easier to develop productive working relationships before potential problems arise; and
- Stakeholders may appreciate seeing their inputs have real impact from early project stages.

Early engagement is not always practicable for a variety of reasons, including the fact that some stakeholders become apparent only after project planning has progressed to a considerable degree.

Stakeholders' concerns can be incorporated into the earliest stages of cable route planning and can include avoidance of specific locations or features.

In a number of cases fishermen have provided their knowledge of the seabed early in cable route development, helping identify cable routes where the seabed is favorable for burial. Both sides recognize that appropriate cable burial is to their advantage to help mitigate potential contact and conflict. Fishermen participation in route development can be helpful in several ways:

- Knowledge of the fishing grounds for conflict avoidance;
- Knowledge of seabed characteristics for identification of favorable burial routes;
- Avoidance of contact between survey equipment and fishing gear (potentially damaging to both);
- Familiarity with other stakeholder groups and their areas of concern; and
- Stakeholder "buy-in" that can support project implementation at several levels.

Some stakeholder interactions may require formal commitments (such as proximity agreements between telecommunications cables and offshore energy installations). At a stage of early engagement, neither side may have the information required to enter into such a commitment. In such cases, a high-level Memorandum of Understanding may be useful to outline general principles, areas of agreement, and ways to progress toward more formal arrangements.

4.4. Marine spatial planning – pressures and conflicts

A National Ocean Policy was established by Executive Order on July 19, 2010 and the National Ocean Council consisting of 27 Federal agencies and departments was created. One output of the Council to date has been a Marine Planning Handbook that provides guidance for regions that may wish to create regional planning bodies and regional marine plans. However, regional planning bodies, if set up, are not regulatory and have no independent legal authority to regulate or otherwise direct Federal, State, tribal, or local government actions. As such, there is no mandate for marine spatial planning in the US and if plans are introduced they will not have regulatory force.

Rather than following the requirements of a spatial plan, cable routing and consideration in relation to spacing, generally follows the guidance of the International Cable Protection Committee in the US:

- ICPC Recommendation No.2 - Recommended Routing and Reporting Criteria for Cables in Proximity to Others
- ICPC Recommendation No. 13 - Proximity of Wind Farm Developments and Submarine Cables

It should be noted that most ICPC Recommendations have been developed with a focus on telecommunications cable experience, engineering and commercial practice. These recommendations are not intended to set firm requirements but rather recognize the need to adapt to particular conditions of each marine area. In the marine environment, ideal conditions for cable routing do not exist. A desired landing area may be fronted by ship anchorages, traffic lanes, dredged channels, steep slopes, rocky seabed, fishing grounds, coral reefs, marine protected areas, telecom cables, and power cables. All of these require consideration and sometimes compromise.

Another characteristic of cable routing that must be appreciated is the tendency for favorable cable areas to become crowded. Cable planners generally want to route both telecom and power cables to densely populated areas where demand for their services is greatest. Many of the shortest and safest routes were taken years ago by early telecom cables. As new cables are planned, it is often necessary to make more compromises in cable length, safety, or both; and to make special arrangements for installation and cable protection.

In order to alleviate cable crowding, some authorities have moved toward requirements of cable removal after service life. This also has limitations and drawbacks. The difficulty of removing cables increases with burial depth. Deeply buried, out of service cables can be very hard to find. Removing a buried cable can be disruptive to the environment, especially in sensitive habitats. Moreover, if a new, active cable has been installed crossing over an old one (a common and necessary occurrence), removal of the old cable upon retirement would require that it be cut at a safe distance on each side, leaving a section in place under the active cable.

Recent growth of offshore energy and power cables is substantial; however, the management of interactions between offshore energy and other sectors such as subsea cables is relatively new. Guidelines and practices are likely to evolve as participants gain experience with these interactions.

5. Factors affecting cable spacing

This section of the report sets out each of the various considerations that need to be taken into account in developing cable routes and determining associated decisions on cable spacing. It is important to note that spacing of cables cannot be considered in isolation and cable route development is a comprehensive process that needs take into account and offset factors of risk and probability drawing upon complex marine data and the requirements of marine stakeholders.

Therefore, the following sections provide a checklist for developers and regulators of the factors that need to be taken into account in defining cable spacing. Where relevant, examples have been given of how cable spacing has been determined for some projects. **However, it is clear from the available guidance and body of evidence from offshore wind projects in the UK and Europe that each project must define its own strategy for cable spacing based on the various and varying factors that inform cable routing.**

In essence project developers need to consider the following key elements during project development and delivery phases and demonstrate due consideration of these factors to regulators:

a. Regulatory process – to determine the seabed licensing and project permit requirements.

b. Project economics – to assure the project stakeholders that the project remains economically viable throughout its life.

c. System / Detailed design – to clarify any strategic design requirements, such as point-to-point versus grid considerations; network operator requirements (connection point and redundancy); to enable the detailed system/project design to take place (including cable routing and burial).

d. Stakeholder issues – identify key stakeholders and their areas of concern so that risks can be mitigated and the project proceeds according to the required timetable. This would include consideration of third party assets, conservation issues and the need for marine spatial planning (formal or ad-hoc).

e. Project delivery – to carry out a tender and contract award process with suitably qualified and competent contractors, to enable the project asset to be built to the required quality and handed over.

f. Project assurance – to be carried out throughout the project process to enable necessary assurance to be given to project stakeholders (i.e., the developer and its partners) that the project is economically viable and can be designed, built and operated to the required standards, safely.

The project life cycle phases can be summarized as follows:

	Project Phase				
Project Discipline	**Project Feasibility**	**Select Option**	**Define Option**	**Construction**	**Operation**
a. Regulatory process	Initiate permit process	Prepare and submit permit applications	Permits awarded	Permit compliance	Permit compliance
b. Project Economics	Check viability of project	Refine project economics	Optimize project economics. Financial Investment Decision	Financial audits	Financial audits
c. System / Detailed design	Initial system design	Refine option designs. FEED	Detailed design. Freeze system design	Address any detailed design changes	Monitor system performance
d. Stakeholder issues	Engage and determine key issues	Discuss options	Agree any mitigations	Keep engaged. Execute mitigations	Keep engaged. Address any issues
e. Project delivery		Preparation of RFP documents	Tender process, appoint contractor(s)	Monitor construction and commissioning. System handover	System operation and maintenance
f. Project assurance	Initial review. Initiate Lessons Learnt process	Peer reviews and address feedback	Peer reviews and address feedback	QA/QC audits	QA/QC audits

The processes that need to be followed in order to define cable spacing have been considered in relation to the above factors to provide an indicative process that captures each of the factors that inform decisions on cable spacing. This is presented in Section 5.1 below.

5.1. Process for determining suitable cable spacing

The flow chart below outlines the processes involved in determining cable spacing.

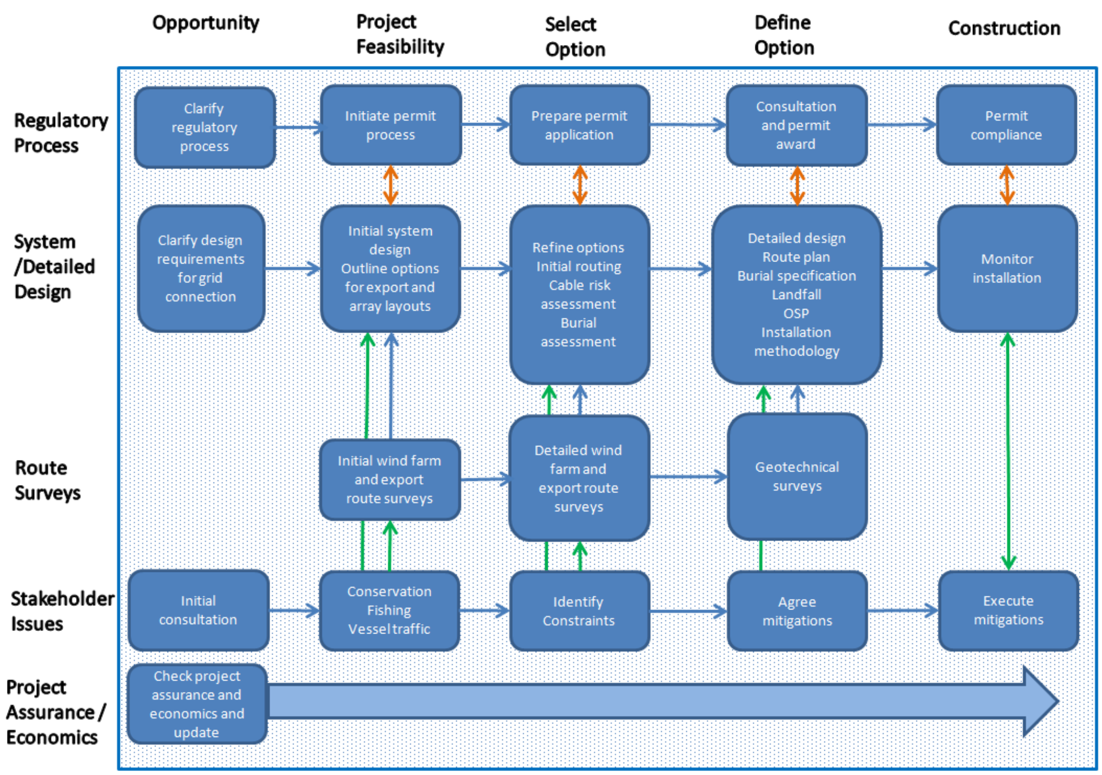

Figure 3. Project Phase Flow Chart

Key considerations include:

- A risk based approach to route engineering, including consideration of route geology, third party assets and key stakeholders;
- Strategic design of the system to meet the requirements of the system operator and redundancy;
- Key stakeholder issues such as fishermen, conservation and navigation and the management of their interactions;
- Ability to install and maintain the cable system;
- Third party access for cable repairs;
- Environmental issues such as EMF; and
- Funneling of the cables close to landfalls and offshore platforms.

5.2. Route design and development

5.2.1. Principles of cable routing

The principles of route engineering and route design for submarine cables are well established and although not overtly specific in covering considerations for cable spacing are key influencing factors in decision making on cable spacing. Route design is based on a number of issues all of which should be considered for relevance and evaluated as appropriate while incorporating the established design strategy (i.e., the issues affecting the route selection, which will include: route geology and seismic activity, third party activities, conservation issues, regulatory an permitting issues). Constraint mapping and threat analysis should be augmented by applied installation and engineering knowledge.

Cable route design must necessarily address diverse issues in order to achieve the key objectives of:

- Achieving maximum cable security;
- Safeguarding system supply through transmission redundancy;
- Achieving cost effectiveness; and
- Managing interactions and conflicts with other seabed users.

The table below outlines the various matters to be considered in route design and development.

Subject	Issue to be addressed	Principal References	Project Phase
a) Basis of Project	i) Demonstrate the overarching rationale for the project location and cable route corridors for development and the generating zone, including, layout and spacing of turbines, location and site selection of OSP, selection of landing point, and other spatial planning issues	5, 6, 7, 8, 9, 10, 11, 12, 16	Feasibility
	ii) Identify all stakeholders impacted or proximate to the cable route corridors for development. Demonstrate an understanding of the impact of the project and how negative impact will be mitigated	5, 6, 7, 8, 9, 10, 11, 12, 16	Feasibility
	iii) Identify a clear development strategy for project cable installation and an O&M strategy for service and maintenance of project cables (planned and unplanned)	4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	Select/Define
b) Project planning	i) Demonstrate the systems, plans and processes necessary for comprehensive understanding, capability, experience and competence to design, develop and complete the project as planned, incorporating industry best practice for marine operations, with appropriate systems and processes	ISO 9000 ISO 18000 ISO 140001 IMCA guidance 15, 16	Feasibility
	ii) Provide information relating to high level project risks, constraint mapping, ground conditions assessment, metocean report and interaction planning	5, 6, 7, 8. 9, 10, 11, 12, 16	Feasibility/Select
	iii) Identify requirements and constraints relevant to cable thermal properties and system capacity	11	Feasibility/Select
c) Permitting and consents	i) Demonstrate an understanding of the regulatory framework pertinent to the project cable route development	1, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16	Feasibility
	ii) Identify requirements and points of contact and establish a permit and consents plan including time lines for activities including; submissions, consultations, responses and all relevant requirements	4, 5, 6, 7, 8, 9, 10, 11, 12, 13	Feasibility
	iii) Identify crossed and proximate assets and develop an interface management plan	4, 5, 6, 7, 8, 10, 16	Feasibility

Subject	Issue to be addressed	Principal References	Project Phase
d) Environmental risk mitigation and management measures	i) Identify the scope of environmental studies necessary ii) Provide a statement or impact assessment as appropriate	5, 15 CFR part 930	Feasibility
e) Route development study(s)	i) Demonstrate a detailed assessment of limitations, constraints, socioeconomic, geopolitical, geophysical, geotechnical and metocean factors that require to be addressed through development of the project to inform detailed planning of data acquisition and design and engineering for the project ii) Identify routes for survey: Desktop research studies (normally with some field work such as site visits and initial meetings with key stakeholders) to ascertain appropriate corridors for cable route surveys. Comprehensive assessment of all the relevant factors is necessary to identify routes and zones for survey, to identify and specify the scope of surveys and inform vessel and equipment specification iii) Reports will provide initial assessment of the engineering scope required and inform of the nature and challenges facing the project	5, 11, 12, 13, 16	Feasibility
f) Cable security	i) Identify strategic issues relating to landfall location and operation ii) Identify proximate assets and third party interests, socioeconomic, geophysical, geotechnical and metocean issues relevant to the environment within which the project cables are to be installed and operated iii) Demonstrate relevant and appropriate geophysical and geotechnical studies have been undertaken to determine the situation along the cable route corridors for development of a cable protection plan iv) Demonstrate that an appropriate assessment of the risks to project cables has been fully assessed and evaluated	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16	Feasibility/Select/Define
g) Engineering design parameters	i) Demonstrate a process for development of a project engineering concept that details the range of engineering options that may be necessary to install the project cables and provide the necessary technical solution (an overall envelope**) ii) This should include and incorporate consideration of the type of installation vessels and equipment that might be utilized at all phases of the project where cables are being or have been installed, not least to understand the impact or risk they may have on ground conditions and/ or installed cable security	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	Feasibility

Table 2. Matters to be considered in route design and development

** For example, in the UK the principle of the "Rochdale Envelope Approach" has been used for consenting and environmental impact. It is named after a UK planning law case, and requires a project description to be clearly defined, within a number of agreed parameters (relating to the scale and footprint of the project), for the purposes of a consent application. This allows for a certain level of flexibility while a project is in the early stages of development. As development progresses and more detail and certainty are available, further information regarding potentially impactful elements of the project can be provided.

In addressing the matters outlined above, a suite of project information is built up. This information feeds into a process of decision making that takes into account all matters associated with cable routing, including considerations for cable spacing.

Initial decisions on defining broad cable spacing are likely to be based on nearby projects or projects located in similar areas in terms of ground conditions, metocean conditions and offshore activity. Examples of this in relation to, for example, the BritNed interconnector cables in Northern Europe are:

- Agreement with the Dutch permit authorities to pre-sweep the active sand wave areas close to the Dutch coast, to reduce the risk of cables being suspended between sand waves as they move across the cable route;
- Route engineering to minimize the crossing of shipping lanes close to the ports of London and Rotterdam and hence reduce the risk of anchor damage to the cables in the future.

5.2.2. Achieving maximum cable security

The provisional route of any transmission network is largely determined by the location of, and distance to, the optimum connection points(s) onshore. This route is further developed using recognized principles of route design and engineering, so that the cables can be configured in an optimal manner within a defined survey swath.

A properly executed desktop study and marine route survey will assess the hazards and determine the nature of the seabed before recommending the most cost effective and secure route to achieve acceptable risk levels.

Typical factors in this regard include:

- Seabed mobility issues (e.g., sandwave movement if present);
- Burial potential of seabed (e.g., types of shallow soils/extent of bedrock exposure);
- Assessment of shipping threat (potential anchor strikes) using AIS (Automatic Identification System) distribution analysis (where it exists) or other baseline studies including assessment of extent of anchorages – existing or planned;
- Assessment of fishing threat (e.g. trawl board strikes, scallop/clam etc. dredging – invasive to seabed – distribution) – AIS may be of assistance in this task too;
- Distribution of hydrocarbon exploration and extraction activities and related infrastructure;
- Distribution of dredging areas or potential dredging extraction areas;
- Distribution of existing or potential dumping sites; and
- Distribution of seabed hazards e.g., debris, wrecks, Unexploded Ordnance (UXO), etc.

A thorough burial assessment will indicate the success and extent of any burial protection with the depth of burial adjusted to take account of the seabed conditions and the extent and probability of any external threats, and can be further developed using the concept of Burial Protection Index (BPI). Work is currently being conducted in Europe (The Carbon Trust in the UK) to further enhance the concept of protection assessment by front end data analysis, the output of which may be a useful reference but which has not been available at the time of this study.

Where cable burial cannot be achieved for geological or environmental reasons, additional cable protection measures may be warranted – e.g., rock placement; mattressing (over short distances), or development of exclusion zones (subject to permitting and consent issues which should be properly considered before committing to a route).

In the United Kingdom there is a non-prescriptive regulatory approach to cable burial and cable separation issues – that is, a case-by-case approach. In other countries within Europe (Germany), it is understood that prescriptive burial depths and separations are required by the regulatory authorities. For example, for parallel laid cables, the German grid operator Tennet requests >= 100m or 3x water depth (DNV-KEMA, 2012). However, there is at least one case where the requirement has been challenged resulting in a relaxation of the requirement for parts of that specific route.

Subject	Issue to be addressed	Principal References	Project Phase
a) Outline planning (and BPI)	i) Determine threat(s) and establish a probability based risk assessment from which a cable protection plan can be derived ii) Develop a burial protection index (BPI) and identify remedial protection media where primary scheme is not achievable iii) Identify engineering solution capable of delivering the protection required iv) Establish parameters for spacing of array cables (e.g. turbine separation, installation equipment foot print, protection afforded, proximate assets, repair scenarios – see Section 5.3, 5.7 for further details)	5, 8, 11, 16	Select. Define for BPI
b) Dynamic effects	i) Determine and define seabed mobility, risk of scour, presence of static or mobile sand waves, tendency for seasonal or storm event deposition or erosion of materials	5, 8, 11, 16	Select/Define
c) Cable burial equipment	i) Design, plan and engineer to meet challenges presented. Review capability of equipment available to the project to achieve maximum viable protection pertinent to the prevailing conditions and circumstances (see Section 5.3 for further details)	5, 6, 8, 11, 13, 14, 16	Select/Define
d) Detailed threat assessment – vessel traffic	i) Conduct a detailed assessment of the threats identified. This may include analysis of AIS tracking data to determine traffic routing, typical activity patterns, informal anchorage areas, vessel size from which anchor size and type may be determined. DTS site visits may also allow meetings with relevant local organizations to discuss non routine activity (e.g., storm anchorages and port contingency arrangements) and the opportunity to view individual vessels in port or in nearshore waters. Observations should also be conducted during survey operation work	5, 8, 11, 16	Select
e) Detailed threat assessment - fishing	i) Conduct a detailed assessment of the threats identified. This may include analysis of AIS tracking data to determine seasonal patterns of each fishery, size of vessels from which the size and type of fishing gear may be determined ii) Relevant information should be captured and fed into fishery liaison program	5, 8, 11, 16	Select
f) Detailed threat assessment – dredging & dumping, hydrocarbons	i) Conduct a detailed assessment of the threats identified. This will require consultation with regulatory and other stakeholders regarding existing and planned licenses	5, 8, 11, 16	Select
g) Detailed threat assessment – seabed hazards & UXO	i) Conduct detailed assessment of threats identified. Wreck search data to be obtained from official charted information and supplemented by local Agencies where possible (e.g. UKHO or in-country equivalent) ii) UXO information; DTS assessment of whether issue is pertinent from historical perspective; specific survey maybe required to locate UXO and effect either removal or post-survey route avoidance	5, 8, 11, 16 5, 8, 11, 16	Select elect

Table3. Factors to be considered in achieving maximum cable security

Spacing to minimize the risk of anchor damage

Anchors pose a significant hazard to submarine cables, being designed to penetrate the seabed. Ships anchors are generally deployed as a temporary mooring or to stop the ship in an emergency such as when the ship suffers an engine failure. Recent evidence would suggest that the incidents of inadvertent cable release while the vessel is underway are more common than was at first believed. Although they remain a rare event, there is still the potential to cause serious damage to a series of cables over a wide area.

To evaluate the risks of anchor damage the scope of the desktop study can be increased to include historical AIS records of shipping. In this context, the probability of multiple cable damage from a ship's anchor can be considered as pertinent.

This type of investigation is not done routinely and the developer will need to make a measured assessment should the transmission cable(s) cross shipping lanes or other areas of high shipping activity. If such a hazard is deemed to exist the degree of cable burial protection can be increased to minimize the risks from such an eventuality. If this is not possible due to seabed conditions or the requirement of any remedial cable protection, cable separation should be increased further. The degree of separation will depend on a number of factors including the type and density of vessels typically operating in the area, seabed conditions and VTS and/or AIS monitoring of the cable route.

To verify the extent of the hazardous areas, AIS data can be used to evaluate the risks in areas of high shipping activity. Although the probability of these events is rare, it remains important to establish the boundaries of any area of elevated risk and adjust the cable spacing accordingly. It is also possible to conduct mathematical modeling to translate specific AIS data into cable fault probabilities. It is not known if this type of modeling can be used to identify an optimum spacing of cables in relatively close proximity. In order to answer this question, risk modeling work would need to be carried out over a small section of the proposed cable route, for example where the cables traverse busy shipping lanes.

To assess the probability of anchor damage the developer will need to evaluate AIS data in areas of high shipping activity. Whilst the incidence level for cable damage is low the potential for multiple cable hits will remain and the developer will need to make a considered decision when advocating specific cable spacing. An overriding consideration will be the requirements of the System Quality and Security of Supply (SQSS) criteria where any amount of risk, however small, could be unacceptable.

Recent case studies have shown that drag embedment can increase in softer soils. Detailed modeling of fluke penetration is therefore recommended in cases where cable routes cross busy shipping lanes or close to vessel anchorages.

5.2.3. Strategic routing for safeguarding transmission integrity

For terrestrial applications in the USA the reliability of bulk electric generation and transmission is regulated by the Federal Energy Regulatory Commission (FERC), established within the US Department of Energy. It also regulates interstate transmission of natural gas and oil. Under its authority, the North American Electric Reliability Corporation (NERC) and eight associated Regional Entities comprise the Electric Reliability Organization (ERO). According to FERC, "Section 215 of the Federal Power Act requires the Electric Reliability Organization (ERO) to develop mandatory and enforceable reliability standards, which are subject to Commission review and approval" (www.nerc.com). At the local level, state and municipal public utility regulators may have additional rules or standards.

The full set of Reliability Standards for the Bulk Electric Systems of North America updated in August 2014 comprise over 1900 pages covering a broad range of reliability and security topics.

It must be noted that FERC does not regulate the physical construction of electric generation facilities, which falls under the jurisdiction of State Public Utilities Commissions. More information and contacts can be found at the National Association of Regulatory Utility Commissioners (http://www.naruc.org/index.cfm) and the related state and local commissions. In the northeastern US, plans for offshore wind farms have been submitted to and ruled on by state boards of public utilities, which have a great deal of authority in their consideration.

The DNV Recommended Practice on Subsea Power Cables in Shallow Water Renewable Energy Applications (Reference ID 16) provides some relevant information on System Security and Quality of Supply pertaining to the optimum spacing of two or more power cables. This should be determined considering project internal and external factors, i.e. a risk-assessed case-by-case determination. Due consideration should be given to the potential repair of a cable and subsequent repair bights.

It is important to note that separation of cables to overcome any issues of transmission integrity by factoring redundancy, and/or increasing spacing between cables, is typically a function of transmission system operator requirements and cost/risk analysis by the project developer. For example, to overcome the issue of dragging anchors outlined in section 5.2.2, it may be necessary to space transmission cables wider or to achieve deeper burial of the cables. However, if this is not possible, another mitigation could be to introduce a traffic routing, so that vessels are diverted around a critical area of the cable route.

Fundamental to the transmission of power from offshore generation is the integrity and reliability of the submarine cable system necessary for maintaining a level of supply to the onshore grid. An effective offshore transmission network therefore, will necessarily have to reassure generators and onshore grid operators of the robustness of their transmission system. Consequently, some principles of separation of high capacity transmission may be necessary to mitigate the risk of significant localized loss of supply, particularly in any areas of concentrated generation. In developing an offshore grid strategy, separation may be augmented by diversity of routing to provide a level of redundancy of supply, although there may be important technical constraints to consider (see Reference ID 17 for further details).

The design of an offshore transmission system in simple terms would typically either be:

- A radial (point to point) link connecting the offshore generation to the proposed grid connection point onshore;
- A radial plus / offshore hub system, which connect a number of offshore wind farms into an offshore grid connection point; or
- A coordinated / offshore grid system, connecting multiple generation assets and enabling the export of power to more than one grid connection point.

The decision on which design to adopt will be influenced by:

- Who pays for and builds the grid connection;
- Timing of the connection, so that this can be in place when the wind farm is ready to generate; and
- Any regulatory or operational requirements.

In the UK and some other European countries, radial links to the proposed grid connection points have been preferred. This has been preferred from a timing and also economic point of view. However, in Germany, an offshore hub system has been developed, where the transmission operators (TenneT in the German North Sea and 50 Hertz in the Baltic Sea) are required to provide the connection to the grid due to the regulatory framework adopted.

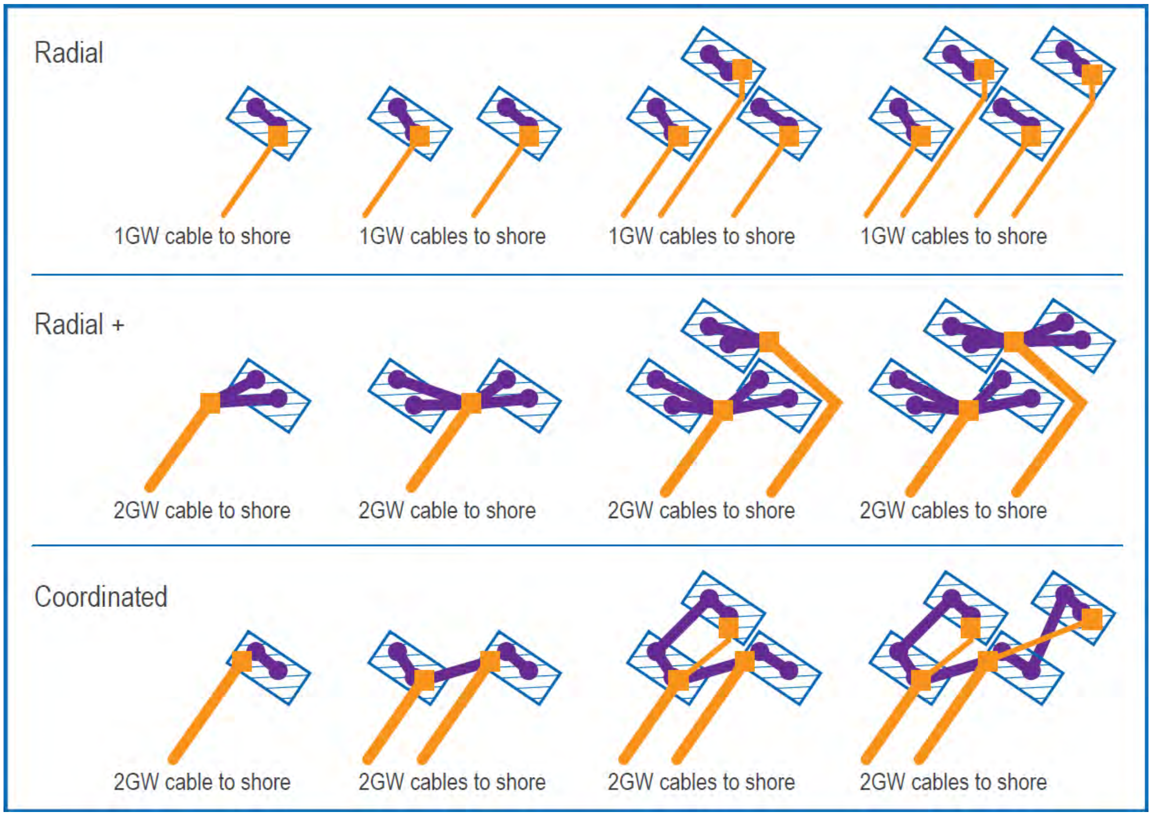

Figure 4. Example of radial, radial plus and coordinated transmission systems (from Reference ID 17)

In redundancy terms, singular point-to-point (radial) offshore transmission network design offers no alternative route to the shore in the event of a failure. In this instance, potentially, an onshore generation plant held in reserve might be activated to cover the loss in electrical output. A hub system is similar to the radial solution in that there is no redundancy in the transmission system unless individual HVDC systems are interconnected.

A coordinated system on the other hand has the potential to reduce the risk by offering alternative transmission routes due to the wider network connections and as a consequence may significantly reduce the system operating costs.

While the initial course of any transmission network is largely determined by the location of the optimum connection point(s) onshore, the ultimate choice of connection point will be determined by finding an economic balance between the offshore assets and the cost of onshore connection and infrastructure.

The choice of radial versus coordinated system could also be determined by the upper limit of power which can be injected or removed from the transmission system at any one point. For example, in the UK, SQSS states that up to 1800MW can be connected by a single circuit, and that radial connections are rated at 100% capacity. For coordinated (grid) elements, connections can be greater than 1800MW provided that alternative power paths are available to redistribute power following loss (Reference ID 17).

In the US the design of the offshore transmission system will be determined at a high level by the regulatory requirements set in place by the US Department of Energy Federal Energy Regulatory Commission (FERC) to link of the offshore generating assets and provide more system redundancy and how the transmission system developers fulfill these requirements. In the absence of formal SQSS requirements in the US, individual projects would need to undertake project specific design risk analysis, with the system operator, in order to confirm that the system design meets the reliability standards set down by the regulator.

Subject	Issue to be addressed	Principal References	Project Phase
a) Array Cables	i) Array cable route design is a function of point to point connection of the turbines and options for optimization of array layout. Some developers have also included a "circular redundancy loop" on the end of strings. Connection to single OSP allows relatively limited range of options. Introduction of a second OSP in larger developments will provide routing options for transmission	**8**	Feasibility/Select/Define
b) Export cables	i) Should the option of transmission redundancy exist and be desired then separation of export cable systems may be achieved through the development of independent routes to separate landing points, increased separation of routes to the same landing point or through a coordinated and branched offshore transmission network in the case of a major or multiple generation base development	**8, 9, 16, 17**	Feasibility/Select
	ii) The degree of separation should be determined through full route design analysis and assessment and consideration of the specific circumstances, present and potential threats and the level of protection that may be afforded to each cable group in a system		Select/Define
	iii) Where a risk of disruption of significant transmission capacity might exist within a short time frame, then there is a risk to system supply to the onshore grid and a detailed assessment of grid requirements will be necessary.		Select/Define

Table 4. Factors to be considered in strategic routing for safeguarding transmission integrity

5.2.4. Routing to achieve cost efficiencies

In the United Kingdom, a National Grid Offshore Transmission Network Feasibility Study (Reference ID 17) identified a number of cost benefits in a coordinated offshore transmission network (amounting to a total of £6.9 billion by 2030) in comparison to a radial design. The report noted that this would be reflected in cost reductions to the consumer both as capital costs and a reduction in operational and congestion management. The report went on to suggest that the potential savings would be largely delivered through a reduction in the required assets to connect the offshore generation, notably the transmission cables.

That study recognized a number of challenges associated with moving towards a coordinated transmission design offshore, but a clear regulatory framework, delivered in a timely manner, would be required to navigate these challenges if the benefits of such a strategy were to be realized.

While the initial course of any transmission network is largely determined by the location of the optimum connection point(s) onshore, the ultimate choice of connection point will be determined by an economic balance between the offshore assets and the cost of onshore connection and infrastructure.

5.2.5. Management of interactions and conflicts

It is generally recognized that increasing the spacing between cables will not greatly increase the overall cable length. To minimize their risks developers may prefer to space the cables as far apart as possible.

Consequently, it is important that all parties reach agreement on mutually acceptable routing and spacing, with acceptable risk levels to the cables, but at the same time allowing the development of other commercial enterprises, a right enshrined in international law (UNCLOS; Reference ID No. 1 – see Section 3 of this report).

It is accepted that at the cable landing zone there may be areas of conflict with multiple high capacity cables interacting as they converge towards the landing point(s). A similar situation will exist offshore, as widely spaced cables converge towards the substations. Any spacing issues in these areas will give way to added protection on the cables, minimizing the increased risks, although the convergence and proximity may have a bearing on engineering of such protection.

The initial assessment of the proposed development will provide an opportunity to identify potential conflicts. Using data from a number of disparate sources the developers will draw up a constraint map to document the environmental concerns and restrictions that might conflict with the potential wind farm site and to plan further investigations with the aim of quantifying any potential impacts or interactions.

With an offshore development, socio-economic constraints will typically range from public opposition at a local level through to limitations imposed by other users such as fishing, shipping, military, oil and gas exploration, telecoms and tourism.

Strategic planning for the operational phase of any cable system should be considered at the development stage. Repair strategy will have a considerable bearing on separation decisions not only for lay-down of the repair bight but also for access to the cables where de-burial and/or removal of external protection may require surface operations to present a risk to other proximate cables. At landfall and OSP locations, and potentially in respect of array cables, a repair scenario may require removal and replacement of large sections of cable and a repeat exercise of the installation operation at that location.

Subject	Issue to be addressed	Principal References	Project Phase
a) Array Cables	i) Close coordination and interface management is the key factor within the wind farm development area. The construction stage will involve a range of operations and activities which may be disconnected from cable installation by some degree. A high degree of effective communication between project package management teams and operational personnel should be encouraged, with close management of critical or less obvious interfaces	7, 8, 12, 13, 16	Construction
b) Export cables	i) During conceptual design and DTS studies, principal stakeholders should be identified ii) The Developer will need to have in place competent and authorized personnel to liaise with third parties; this normally involves establishment of a marine co-ordination division within the Developer's organization iii) Close co-ordination is typically required with coast guard, port/harbor authorities, military authorities, representatives from fishing associations/national bodies, third party asset owners (cable and pipeline owners) and third party agents (e.g., warranty surveyors) throughout the project delivery phase iv) Controlled notification of marine activities to include notices to mariners, navigation warnings, proximity warnings/temporary exclusion zones	5, 7, 8, 11, 12, 13, 15, 16	Feasibility - Construction
c) Cable security	i) Consideration to use of guard vessels during installation and between installation of cables on seabed before burial (if synchronous lay and burial is not possible there may be substantial periods when the cable is on the seabed before burial or other cable protection measures can be conducted). Guard vessels may patrol unburied cable sections ensuring that, principally vessels in transit and/or fishing vessels do not approach the unburied cable sections ii) The value of educating third parties in the presence and purpose of cables should not be underestimated and regular and widely distributed information relating to cable installation activities and the presence of cables in operation has been shown to enhance cable security.	8, 12, 13, 15, 16	Construction

Table 5. Management of interactions and conflicts

5.3. Spacing for effective engineering during installation

The installation of cables in close proximity to existing cables will present a hazard by virtue of proximate operations and a constraint that may otherwise not exist. The developer will need to consider various factors as described elsewhere in this report, including the limitations of current cable installation techniques, procedures and equipment when advocating a specific cable separation.

Bipolar HVDC export cables can be installed as a bundled pair or individually with an effective separation largely defined by installation engineering requirements as discussed below. In shallower waters however, the electromagnetic field (EMF) of HVDC cables may be a relevant factor (refer Section 5.5 below.)

Where two cables can be bundled together and installed synchronously, only one field installation operation is required, but other factors related to the engineering need to be considered and addressed. While bundling of cables may appear to be a cost effective strategy for implementation and seems to offer less impact on the environment and other seabed users, additional costs related to engineering and constraints on the capability of equipment to effectively and safely handle bundled cables are relevant and initial assumptions may not be realized. Proper consideration should be given to the cable type and its properties and the risk of introducing latent defect through mishandling before committing to any particular strategy. Improved design of subsea equipment and/or type approved cable, may result in a wider range of acceptable options in the future. While simultaneous lay and burial of bundled cables is presently not commonly employed, post-lay-burial of bundled HVDC cables is currently accepted practice.

Where two cables are separated then the minimum distance between them is generally a factor related to the footprint of any seabed installation or burial equipment. If one considers the maximum width of any such machinery currently available to be in the order of 10 to 12 meters, a corridor of 30 to 50 meters between each cable will alleviate any risk to either cable during installation and subsequent burial. The operational footprint of a submersible vehicle will vary with its type and operational requirements. For instance, a towed plough is restricted in its maneuverability while a tracked vehicle may require more seabed space to operate around the cable. The figure of 50 meters is based on historical data where two HVDC cables were separately laid in this manner while another project under construction at the time of writing this report has a design separation of 30 meters.

In the modern era, all installation and maintenance vessels engaged in wind farm related operations use sub-meter accuracy navigation systems (including typically Differential Geographical Positioning Systems (DGPS) systems as a main reference). Many vessels operate in-field using dynamic positioning systems (DP) whereby the vessels' position can be maintained on location or can move in a very controlled manner, linked directly to the navigation systems employed. When environmental forces such as high winds, waves and/ or tidal currents exceed the capabilities of a DP system or the vessel's ability to maintain position by any means, operations may be temporarily halted, and in more extreme cases suspended, which may necessitate the planned cutting and lay down of the sealed cable end for subsequent recovery. The key for managing this aspect is access to reliable site specific weather forecasting and project planning. In exceptional circumstances a cable may be cut away from the vessel for safety reasons, until such time as operations may be safely resumed. The location of the cable on the seabed in such circumstances may not be on the planned route.

In some circumstances installation of a cable system onto and into the seabed may require preparatory works. These may include such tasks as: removal of any identified UXO; removal of specific items of debris or individual boulders that may pose a problem to the planned installation and cable burial method; undertaking a pre-lay-grapnel run to remove ropes/nets and third party out-of-service cable removal; dredging in specific areas of sandwave development/mobility to improve the cable route for installation; the installation of mattresses on the seabed over in-service cables and pipelines, or rock placement to stabilize material or infill the seabed contours.

In the coastal landfall section of a development, due consideration will necessarily have been given to the use of pre-installed conduits through which cables may have to be installed for cable protection purposes, or open cut trenches. Directional drilling techniques are common to circumvent environmentally sensitive coastal habitats. Thermal considerations will also be taken into account throughout all of the engineering design stage and it may be that one or more conduits are used to separate the cables in the landfall to mitigate potential overheating. The physical properties of the cables are also carefully considered such that bend radii are not exceeded.

It is normally preferred to land a shore end directly from the main lay installation vessel and then to lay cable seaward, but this may not always be appropriate. In shallow coastal waters particularly, shore end landing operations may be conducted as a separate and discrete operation to a depth of water where the main cable lay vessel can safely operate.

Engagement of competent professionals versed in marine operations and submarine cable operations are key to project success where the circumstances of the project, location, cable and equipment must be fully assessed. Employed in various roles such as for assurance, third party verification or as insurers' surveyor, a key basis for the assessment will be good industry practice.

Subject	Issue to be addressed	Principal References	Project phase Factors
a) Array Cables	i) It is not envisioned that spacing between array cables within the wind farm development area (except in the approaches to OSP) is a likely issue. Importantly however is the issue of spacing between array cables and proximate or crossing cables transiting through the wind farm development area	1, 4, 5, 6, 7, 8, 10, 11, 13, 16	Select/Define
	ii) Planning for transiting cables, either existing or future (e.g., export cables to other OWF development) will need to be considered as for all cables in proximity. It may be appropriate however to create a transit corridor by increasing the lateral spacing between rows of turbines and optimizing the route design accordingly	1, 4, 5, 6 ,7, 8, 9, 10, 11,13, 14, 16	Select/Define
	iii) Where the proximate or crossed cable is a third party's then proper regard should be had for the appropriate recommendations and guidance and early dialogue is encouraged	4, 5, 6, 7, 8, 10, 11, 13, 16	Select/Define
	iv) Separation should consider installation equipment and the requirements of operational contingency	7, 8, 10, 11, 13, 14, 15, 16	Select/Define
	v) Separation should consider O&M planning repair strategy	6, 8, 10, 13, 14, 15,16	Select/Define
b) Export cables	i) Principal design concept (single or paired cable solution, HVAC/HVDC configuration; bundled or separated) will guide initial separation concept	8, 9, 10, 11, 13, 16	Feasibility
	ii) Installation vessel capabilities and capacities should be considered– cable load length consideration and possible need for in-line jointing between segments laid at different times. Increased separation locally may be needed at jointing bights. This will be dependent on vessel characteristics (working room), water depth etc.	8, 14, 15, 16	Select/Define
	iii) Cable separation may be influenced by availability of resources and types of vessels capable for installation. Some vessels may only be capable of single cable deployment requiring two-pass installation (i.e., not bundled). Second cable may therefore be displaced from first cable	8	Select/Define
	iv) Detailed post-survey route design based on survey results and BPI studies will identify optimal burial strategy and suitable burial tools. This in turn may dictate separation as some tools/methodologies will require wider separation between non-bundled cables than others for safe working practices	5, 8, 11, 16	Define
	v) Third party cables and pipelines may be crossed; spacing on non-bundled cables may converge locally to achieve single crossing point covered by a single engineering solution; alternatively two crossings may have to be effected. Due consideration as to best practice for crossings is required which will	1, 4, 5, 6, 8, 11, 16	Define

Subject	Issue to be addressed	Principal References	Project phase Factors
	involve early stakeholder dialogue		
	vi) Separation must consider O&M planning repair strategy	6, 8, 10, 13, 14, 15, 16	Define
c) Cable security	i) Cable security is best achieved by suitable cable protection measures that may be decided upon by the assessment of external risks and potential mitigation measures; adequate cable burial is the principal factor, given geological constraints. If satisfactory burial cannot be achieved, external protection should be considered	8, 11, 13, 16	Define - Operations
	ii) In the vicinity of turbines and OSPs then scour protection methods may be warranted to safeguard cables from environmental forces. In the coastal zone/surf zone cut trenches or directional drilling may be warranted to adequately protect the cables	8, 11, 13, 16	Define - Operations
d) Engineering design parameters	i) Cable protection in congested waters may need to adopt specific techniques relevant to the situation. These might include such measures as the application of external armor protection or extensive hand jetting, both techniques commonly require diving operations	8, 11, 13, 16	Define/Construction
	ii) Regulators may be approached to consider no anchoring and/ or no fishing zones to give protection around congested critical infrastructure sites	5,6,8,12, 13.16	Define

Table 6. Spacing for effective engineering during installation

5.4. Spacing to minimize risk during cable maintenance

As part of overall Operations and Maintenance plans, Developers must consider the repair and maintenance of adjacent cables and in particular the risks associated with the fault location, recovery, repair and deployment of the repair bight on the seabed.

With a bundled HVDC cable pair there will be a requirement to repair two cables and possibly a fiber optic cable, with the assumption that all three cables 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 repairs vessel layout and prevailing weather conditions at the time of laydown operation. Therefore, when considering initial cable spacing of two export cables in relatively close proximity, the separation must clearly allow for potential repairs to the cable including its recovery (by ROV or more usually by de-trenching grapnel) and redeployment – while also bearing in mind proximity to turbines, OSP's and any third party cables or pipelines. It is, therefore, not possible to specify a cable separation in this context; a case-by-case assessment must be made. For further details on guidelines the reader is specifically referred to Reference ID 7 and 8 as listed in Section 3 of this report.

For the repair of array cables, the short cable lengths and restricted location within the wind farm array usually means cable replacement is the only viable remedy. Due consideration must be given to the deployment of suitable vessels and support craft given the navigation restrictions. Use of jack up barges/platforms and anchored platform solutions (with due care for proximity of other array cables) may be considered. Risk analysis and mitigation is clearly the key here.

At the landfall approach and at the landing point, as previously discussed there are numerous design and installation constraints; the options for cable repair in the shore end section are limited without re-installation of the entire shore end. Cable recovery in very shallow water or on drying seabed is usually only feasible by mechanical means which may involve limited works during times of low water. Typically this may be achieved from barges designed to bottom out adjacent to the cable affording a stable platform on which to place mechanical diggers. Due consideration needs to be given to all aspects of safety and any other cable shore end proximity.

5.5. The effects of induced EMF on navigation and ecology

In this Section, principal references are Reference ID 8 and 11 as detailed in Section 3 of this report.

An electromagnetic field (EMF) is a combination of an electrical field (created by voltage or electrical charge) and a magnetic field (created by an electrical current). In subsea cable design it is common to block the direct electrical field from HV cables using conductive sheathing. Thus the EMF from both HVAC and HVDC power cables emitted into the marine environment are the magnetic field and the resultant induced electrical field.

The characteristics and strength of the magnetic field vary based on whether AC or DC is being transmitted and the configuration of the cables: whether the transmission is in 3 phases bundled together for AC or whether single (monopolar), bipolar (two cables bundled together) or coaxial cables for DC. In all cases, the EMF strength is proportional to the current and surrounds the core concentrically; the EMF of power transmitted at a voltage of 170kV is less than one-quarter of that transmitted at a voltage of 36 kV (reference 11).

EMF issues have in the past caused concern for marine navigation (can affect vessel magnetic/gyro compasses in certain configurations and proximity) and for certain species of marine organisms – notably elasmobranchs (cartilaginous fish, that include sharks, rays and skates). It is noted that EMF effects operate over only a very short distance – a few meters - from the core of the cable.

- In three-phase AC systems, the magnetic field around the cable is zero, as the sum of the currents in the three phases is zero at all times
- In monopolar DC systems strong electromagnetic fields are generated along the single cable
- In bipolar DC systems (two DC cables laid very close to each other) the result is that the magnetic fields from each effectively cancel each other out. For co-axial DC cables the same resultant effect is observed. This is explained in a little more detail below

In a bipolar DC system with two parallel conductors, the magnetic fields of the currents in the forward and return conductors are counter-rotating. The two fields are superimposed on one another, and if the distance between the two conductors is small, then they will cancel one another out - and the resulting magnetic field will be zero at a certain distance from the cable if the forward and return currents are equal. For the coaxial cable, the superposition of the magnetic fields is totally integrated, the resulting magnetic field around the cable surface will also be zero.

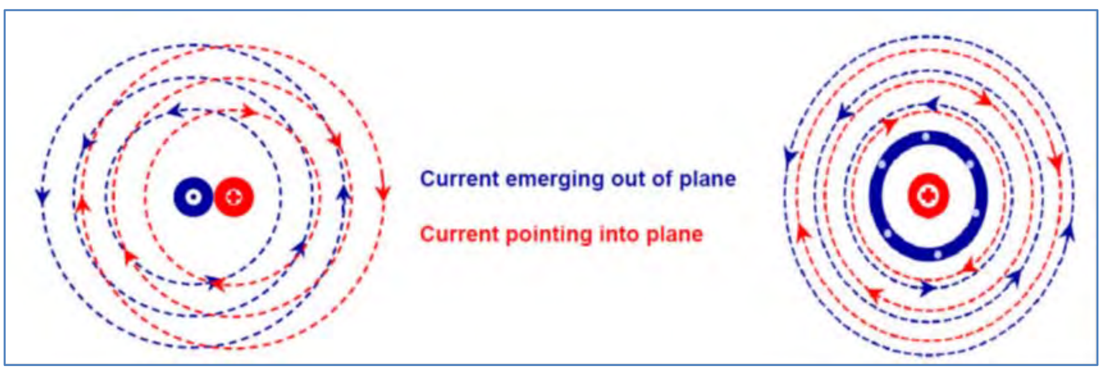

Figure 5. Magnetic field around a parallel DC bipolar cable (left), with currents in opposite directions and around a DC co-axial cable (right), with opposite currents in the inner and outer conductors(Source: Reference 11 refer Section 3 for full reference details)

In terms of cable spacing and marine navigation issues, there may be concerns about potential interference to ships' magnetic/gyro compasses. However, modern navigation techniques do not solely rely on magnetic or gyro compasses; their use remains widespread on leisure craft and as a contingent system and often as a regulated requirement on commercial and other vessels (commercial vessel navigation almost always utilizes gyrocompasses as the principal directional reference with GPS based systems operating alongside or in conjunction with the GPS – which is not affected by EMF fields from a power cable in any configuration). This specific issue is seen as being of relatively low importance – nevertheless, it is still a factor that may need to be considered as part of overall design depending on legislative requirements and local vessel activity. Some authorities may require that in shallow water, HVDC cables be bundled to become a bipolar configuration, whereas in deeper water - where they will have little influence on surface navigation - they can be laid separately and spaced apart.

The coincidence of shallow water and confined navigation channels is most prevalent in the approaches to ports; consequently the greatest significance is put upon compass deviation by port authorities and other related regulatory bodies. In many cases the influence of a cable route upon a navigation channel is over a relatively short distance.

Clearly, in initial system design it would be desirable in any case to avoid shipping channels (or cross them as perpendicular as possible) wherever feasible. EMF/navigation issues may then be of less concern *per se*. Key to this subject is a thorough desktop study and engagement with regulatory authorities at a very early stage of the process.

In terms of environmental impact of EMF on marine species, there has been relatively little study on this issue; some research would suggest a response whilst others do not (Reference ID 8). A competent desktop study should identify the types of species prevalent in a development area (usually conducted in association with an analysis of fishing vessel activity). Where there is no concentration of elasmobranchs or other electrosensitive marine species, then this issue may not be significant. Even where there may be a concentration of these species, it is not necessarily the case that their existence could influence principal AC/DC design considerations or cable spacing (monopolar DC/bipolar DC systems) when so many other strategic factors have to be taken into consideration alongside this particular issue.

Subject	Issue to be addressed	Principal References	Project phase Factors
a) EMF	i) Has the environmental impact been assessed appropriate to the route?	**8, 11**	Select
	ii) Has the navigational impact been assessed appropriate to the route?	**8, 11**	Select

Table 7. EMF factors for consideration

Recent monitoring studies presented by the Basslink and BritNed interconnector cable projects have indicated that EMF impacts upon ships compasses and marine life are within the levels predicted in the relevant environmental impact studies and neither has had a significant adverse effect on navigation or marine wildlife.

5.6. Funneling at coastal connection points

Numerous issues affect the principal spacing of cables at coastal connection points. The issues are often inter-related and can only be balanced by a holistic approach and development of an integrated design plan that takes into account the strategic needs of the stakeholders involved, local ground and marine seabed/sub-seabed conditions, environmental conditions, permitting and regulatory regime, as well as considerations of system security, installation and operation/maintenance. Each project has, therefore, to be considered on a case-by-case basis.

The initial concept of the project will drive principal system design and primary number of export cables attempting to land at a coastal connection point. Clearly the size of the development, the number of potential turbines and distance from shore will materially influence whether the system is likely to be HVAC or HVDC in concept. Where HVAC, multiple cables may land at a coastal connection point (typically 1-3 depending on project size and system voltage); where HVDC if co-axial then, only one cable may land but if not coaxial then the possibility of two cables (and possibly a fiber-optic cable) may land. These may be separate or bundled together.

If a coastal connection point is strategically significant in terms of being a pivotal onwards connection point to the electricity grid system then it may be that more than one development may be obliged to use it. Analogous to telecommunication cable systems, it is often the case that a landing is used by one or more cable network since the onward connection to the grid is established and suitable infrastructure, ducting, transmission facilities etc. may already exist. Often facilities are built with future development in mind.

Submarine cables will be jointed onto the onshore cables in a jointing pit or chamber. Typically a pit will have a concrete base and be supported by sheet pile walls and will be backfilled after the joints have been made. A chamber will be an in situ or pre-cast concrete box. The pits will be designed to be large enough to facilitate the jointing of submarine to onshore cables. Typically for an HVAC or DC cable system they could be 12m x 3m and will be backfilled after the joints are made.

Cable spacing will be significantly constrained by ground conditions in the coastal approach; water depth plays an important role here in that separate shore ends may be required if there are extensive coastal flats or drying areas such that direct landings from an offshore vessel cannot be managed. The industry employs a range of shallow draft installation vessels developed for HV cable systems to bring the heavy cables as close to the shore as possible but even so there is often a need to join the offshore cables to cables already installed in the shore end. Typically shore ends will use cut trenches or, in environmentally sensitive areas directional drilling – bypassing coastal dunes for example where they are of ecological significance. Coastal areas are often fringed by bedrock; clearly this is a more difficult medium to drill or trench through. Detailed coastal site surveys will be warranted to optimize routing and minimize engineering costs. Projects can be future-proofed by installing additional ducting or onshore transition bays, or by reserving space for future connections, as required.

Cable burial affords the best overall cable security solution; once again detailed site appraisal is warranted to design a suitable cable burial strategy; cable lay and burial must be mindful of existing or planned third-party infrastructure (e.g., cables, pipelines or outfalls) ensuring that spacing is such that these assets may be accessed for maintenance, repair or installion. The spacing of power cables may also be dictated by the availability of resources to undertake the burial work. For example, where mechanical diggers are able to access the beach, their footprint may be of the order of 5 meters; whereas shallow barges using jack up legs have a footprint maybe 10's of meters wide.

Permitting and consents; issues of land ownership; access; safeguarding the public; and health and safety issues are all aspects that feed into the engineering design and installation strategy in the coastal zone. Clearly engagement with all stakeholders at the earliest onset of project activities is desirable.

Conservation issues, in coastal locations such as saltmarshes or mudflats, can be key in determining spacing close to the shore. For example, a developer may be forced to "squeeze" their cable(s) into a narrower landfall area in order to avoid the sensitive area, or constrained in their methodology to minimize impact on the sensitive area. An alternative is for the developer to route their cable(s) to another landfall, to avoid the sensitive area altogether, so that their installation is not unduly constrained in method or timing. Early consultation with the stakeholders is recommended so that their issues can be understood and the viability of a given cable landfall determined early in the project.

It may be appropriate to consider establishing a no-fishing and/or a no anchoring corridor either side of the installed cable – especially in areas where the target depth of burial may not have been achieved; this would protect the cable further and also warn potential seabed users of a hazard to be avoided. In coastal waters, leisure craft will often drop anchor outside designated anchorages to conduct sports fishing activities.

An example of export transmission cables fanning from a coastal landfall is provided below.

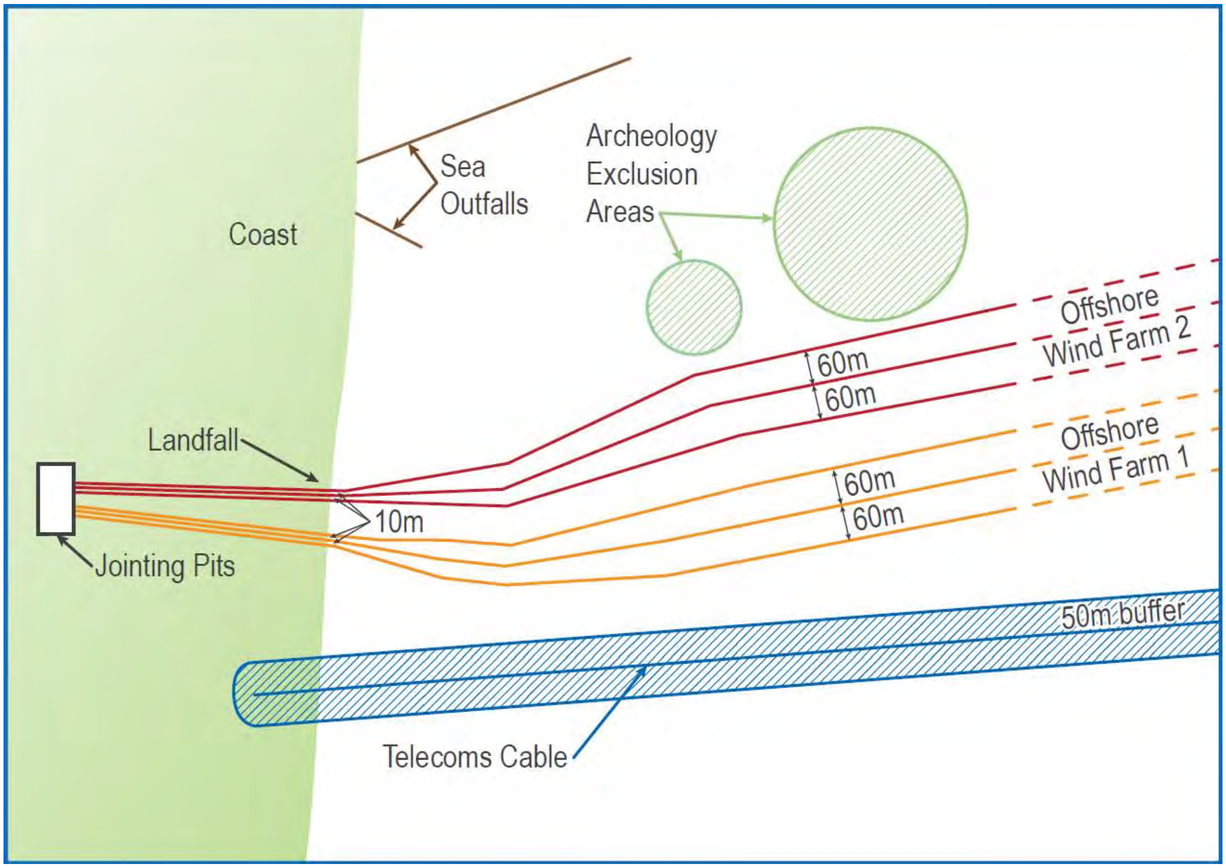

Figure 6. *Example of example of export transmission cables funneling from a coastal landfall (reproduced courtesy of Greater Gabbard Offshore Winds Ltd, Greater Gabbard OFTO plc and RWE Innogy UK Ltd)*

This illustrates the congested nature of some landfalls, even along a straight section of coast. Along with two sets of export cables, there are two sea outfalls located 500-700m to the north and a telecoms cable 200m to the south, along with archaeological restriction zones in the approaches. This all goes to make the landfall challenging to design for cable installation, so that each set of cables can be safely installed. In this instance the cables are spaced at 60m offshore and then fan in to HDD ducts at the shore spaced at 10m intervals, over a distance of 500m. There is a gap of around 50m between the cables from the two projects. The jointing pits are spaced at around 5m. .

It should be emphasized that these separations have been developed on a project specific basis, given the project specific risks involved and in consultation with the key stakeholders. The above should not be taken as standard dimensions for future projects.

Subject	Issue to be addressed	Principal References	Project Phase
a) Strategic routing	i) The selection of an optimum landfall may be heavily constrained by the capacity of the onshore grid for connection. The amount of generated power and the capacity of the cables will influence the number of cables landing, and consequently, the congestion in the approaches	8, 9, 11, 16	Feasibility/Select
	ii) Consideration might be given to separating connection points despite potentially longer cable routes, to reduce congestion and to mitigate the risk of significant supply failure	8, 9, 11, 16	Feasibility/Select
b) Interactions and conflicts	i) Coastal zones may see an increase in shipping activity and leisure craft along with continued commercial fishing activity. Effective engagement with these sea and seabed users is required in a controlled manner	5, 8, 12, 13, 15, 16	Construction/Operation
c) Installation engineering	i) Landfall environmental, consenting and engineering requirements largely dictate the methodology for the design and engineering of cable landfall	5, 11, 12, 13, 14, 16	Select/Define
	ii) The dynamic nature of the coastal environment creates special circumstances which will require specific assessment and analysis, including consideration of additional stabilization of cables that might become exposed or which cannot be buried	5, 11, 8, 13, 16	Define - Operations
	iii) Separation should consider O&M planning repair strategy	6, 8, 10, 13, 14, 15, 16	Define/Construction
	iv) Regulators may be approached to consider no anchoring and/ or no fishing zones to give protection around congested critical infrastructure sites	5, 6, 8, 12, 13, 16	Define

Table 8. Funneling at coastal connection points

5.7. Funneling at offshore connection points

Offshore connection points usually comprise Offshore Substation Platforms and AC/DC Convertor Offshore Platforms. The number of OSP's will be determined by the size of the wind farm development: an OSP will typically be designed to handle 250-300MW of export capacity, so there would be two OSP's for a 500MW wind farm. Typically, the OSP will be centrally located in the wind farm in order to optimize the array layouts. However, this may be modified locally to take account of seabed conditions, such as geology, mobile sand waves, location of third party assets (cables or pipelines), navigation features or hazards (e.g., UXO). A further consideration will be the need for a suitable export cable corridor from the OSP to the edge of the wind farm and the possible need to interconnect two OSP's within a single wind farm array. No two wind farm developments are the same in this respect.

Should the wind farm require a HVDC connection to shore, a convertor station is normally located at the edge of the wind farm to connect the HVAC and HVDC systems.

Cable spacing into an OSP will be constrained by the number of array cables coming into the OSP and the need for a "cable free" zone, typically on one side of the OSP, for the use of construction or maintenance jack-ups, see Figure 7 below. Other factors include the design of the OSP platform itself (several design types may exist depending on water depth, geological/foundation design/environmental factors) and the location of the Export Cable J or I tubes on the OSP.

Distribution of seabed stabilization material, scour protection and other seabed infrastructure around the OSP should be considered in developing the cable routing plan. The importance of early and maintained coordination between platform developers and the cable system developer is an important factor.

Due consideration must be given to installation methodologies of the array cables into the OSP and to maximize cable spacing between array cables to afford best options for any maintenance or repair operations that may be warranted.

The spacing of export cables from the OSP to the edge of the wind farm through the wind farm area will be governed by the same principles of maximizing separation and ensuring optimal cable security as for export cables outside the wind farm area.

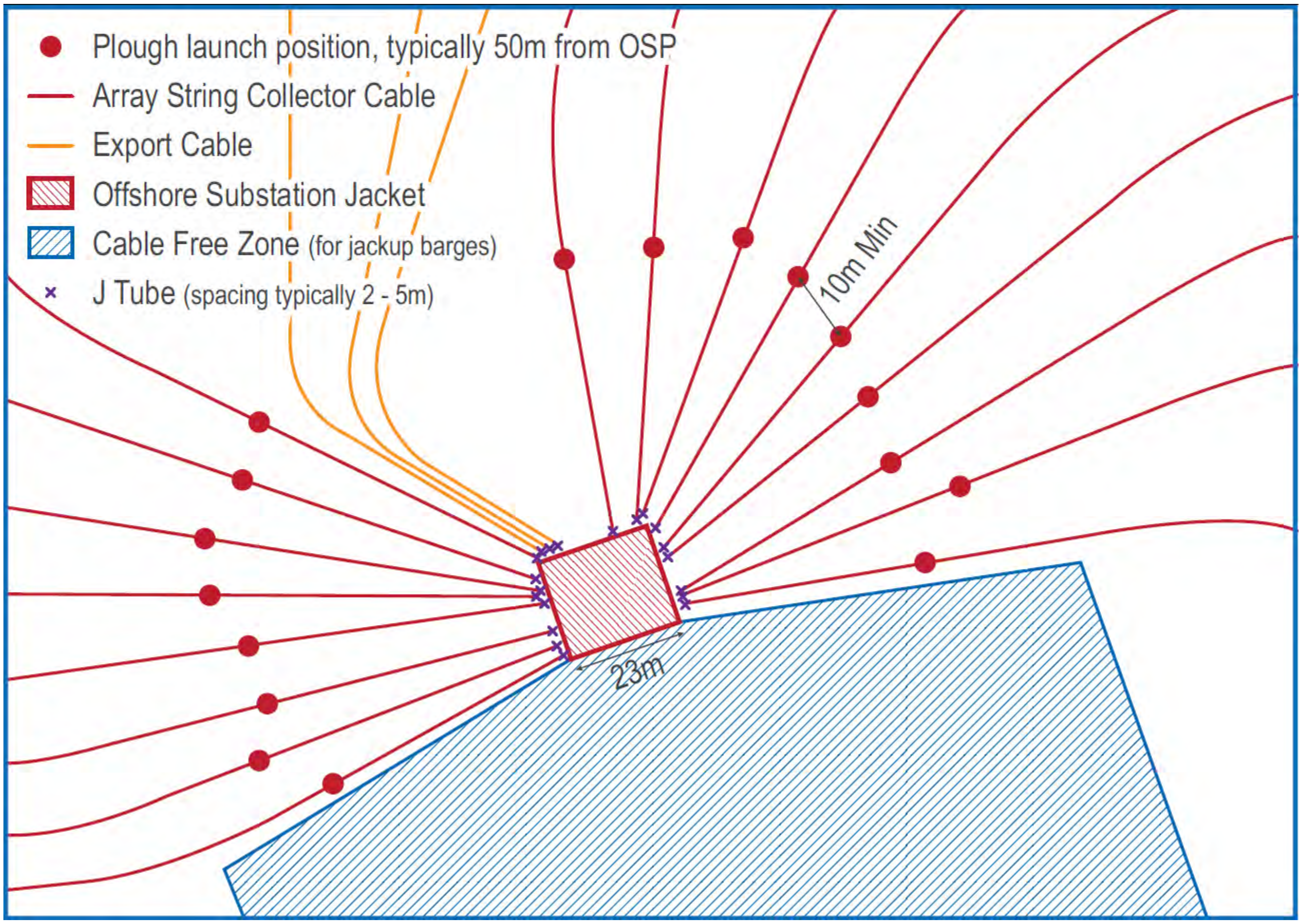

Figure 7. Example of OSP layout with export and array cables and "cable free" zone (reproduced courtesy of Greater Gabbard Offshore Winds Ltd, Greater Gabbard OFTO plc)

Figure 7 shows an example of export and array cables funneling out from an OSP. In this case, there are 3 export cables and 17 array collector cables. As with Figure 6 above, this illustrates the congested nature of the seabed around an OSP and the need to properly consider risks when designing cable separation. In this case, j-tube separation at the platform ranges from 2-5m (determined by the design of the OSP jacket foundation). The cables were installed by plough burial. The plough launch position (for cable burial) was set at 50m from the OSP, to ensure that there was sufficient separation (10m) from adjacent cables when installing and to allow a degree of separation for maintenance purposes. Also shown is the "cable free" zone, on the south side of the OSP, to allow jack-up vessels to set up for installation and operational purposes.

It should be emphasized that these separations have been developed on a project specific basis, given the project specific risks involved. The above should not be taken as standard dimensions for future projects.

Subject	Issue to be addressed	Principal References	Project Phase
a) Strategic routing - array and export cables	i) Consideration should be given at the design stage as to the routing of cables to the OSP, including consideration of the platform type, 'J' or 'I' tube configuration and distribution, seabed stabilization and scour protection and any mooring requirements	11, 13, 16	Select/Define

Subject	Issue to be addressed	Principal References	Project Phase
b) Interactions and conflicts	ii) Close coordination and interface management is the key factor within the wind farm development area. The construction stage will involve a range of operations and activities which may be disconnected from cable installation by some degree. A high degree of effective communication between project package management teams and operational personnel should be encouraged, with close management of critical or less obvious interfaces	7, 8, 12, 13, 16	Construction
c) Installation engineering – array and export cables	iii) Consideration should be given at the design stage as to the routing of cables to the OSP, including consideration of the platform type, 'J' or 'I' tube configuration and distribution, seabed stabilization and scour protection and any mooring requirements	11, 13, 16	Select/Define
	iv) Separation should consider O&M planning repair strategy	6, 8, 10, 13, 14, 15, 16	Define

Table 9. Funneling at offshore cable connection points

5.8. Summary of key points raised in this section

The items below highlight the key points pertinent to cable spacing from the above sections:

- There are no prescriptive answers to cable separation issues in relation to wind farm development matters; each development must be considered on a case-by case basis taking proper account of all relevant factors and using a risk based approach. In this regard, input from regulatory/permit requirements and stakeholder consultations is a key part of the project and needs to be incorporated in a holistic design process. Regulatory, permit and stakeholder issues have been summarized in Section 4 of this report.

- The key to assessing cable spacing on a macro scale is the wind farm location and hence whether an HVAC or HVDC system provides the most cost effective solution for efficient energy transfer to the grid.

- At a strategic level, consideration should be given to an offshore grid system as well as a point-to-point approach for grid connectivity. In this regard, early dialogue with the regulator and system operator will be required.

- Coastal landings will most often be dictated by onward connectivity to the electricity grid system; several developments may potentially use the same landfall.

- Comprehensive desktop research into constraining factors is fundamental to understanding risks to cable routing, and therefore, cable spacing. Schedules and budgets should allow for this costly and time consuming, yet important, inclusion.

- Guidance has been given by way of external references as to how to space cables in proximity to one another and with respect to other third party cables or pipelines and also with regard to in-field assets such as wind turbines and OSPs. Referenced documents describe a suitable approach to working close to these assets for installation and operations and maintenance of the installed cables.

- Consideration should be given to potential for future developments in the industry that may impact upon the content of this study and of reference documents.

- Research and decision processes should be based on the proper assessment of identified risk.

6. Conclusions and recommendations

It is evident that there is a raft of guidance available to inform cable routing and that various guidance makes reference to considerations for cable spacing. However, it is also clear from the information above that it is impossible to extract considerations for cable spacing from the full gamete of considerations that inform cable route design. Cable route development is an holistic and iterative process that must include factors affecting cable spacing and demonstrate cable spacing decisions have been deliberate and based on all relevant factors which can include:

- Electrical system design;
- Stakeholder requirements (Reference ID's 5 -12, 16);
- EMF impacts (Reference ID's 8, 16);
- The need to take into account space constraints and congestion at landfalls, offshore and within wind farm arrays (Reference ID's 5 -11, 15, 16);
- Safeguarding transmission integrity (Reference ID's 8, 9, 16, 17);
- The need to be able to safely install, repair and maintain cables adjacent to one another or other infrastructure without posing intolerable risk to those adjacent assets (Reference ID's 4 - 11, 15, 16);
- The relationship between burial depth and cable spacing (Reference ID's 5, 8, 11, 16).

The offshore hydrocarbon and telecoms industries have adopted best practice techniques and much of this has already been adopted and adapted for use in the growing offshore wind industry, principally in Europe. Studies conducted to date reinforce the conclusions of this study and common practice in all operations in the marine environment

It should also be noted that each guidance document or regulation has been created for a specific purpose, and in some cases it could be possible to conclude that some of the guidance or requirements are contradictory, which further evidences the need for case by case decision making based on consideration of all of the relevant factors. For example, the TAP671 report (Reference ID 11) recommends a 500 m wide (250m either side of the centerline) right of way corridor whilst BOEM currently requires a 200 ft right of way corridor for offshore wind farm cables. Often it is advantageous to allow a wide corridor of search initially which is iteratively narrowed down via the route design and development processes outlined in Section 5.2 above. This iterative approach allows developers to select the most appropriate route that takes into account the requirements of other marine stakeholders, environmental sensitivities, ground conditions and cable burial requirements.

There is no substitute for detailed planning or for full and proper consideration of the relevant factors affecting cable routing and, therefore, spacing decisions. In practice prescriptive solutions to cable spacing have been found to be inappropriate but a suitable solution may be derived after consideration of the many relevant factors that affect a given situation. It is often the case that, given the multiple factors to be considered, an acceptable compromise must be reached in determining the most cost effective result.

This is evidenced by the fact that where prescriptive requirements for cable corridors, cable spacing or burial are in place, they have often been challenged by developers in order to optimize factors of cost and risk. Examples of this are some of the prescriptive spacing and burial depth requirements in the German North Sea sector, which have been successfully challenged by developers. With this in mind it is suggested that specifying cable spacing in regulations is not the most effective manner in which to ensure appropriate cable spacing. Instead developers should demonstrate consideration of the factors that influence cable spacing. The federal regulation CFR 585 (Reference ID 12) already requires a Facilities Design Report, Construction and Operations Plan, Fabrication and Installation Report, Site Assessment Plan and General Activities Plan – these documents should evidence that the considerations detailed in this report have been taken into account as necessary with regards to cable spacing.

Recommendations arising from this study and the drafting of this report are outlined below:

- The appropriate authorities (including grid operators and authorities regulating grid matters) should be cognizant of the relevance of spatial planning, particularly in areas with potentially congested or conflicting interests to allow flexibility to bring power ashore where it is most beneficial.

- Matters should be considered on a case-by-case basis taking full account of the prevailing circumstances and conditions that may influence the integrity of a cable throughout its design life.

- A risk based approach should be taken when considering routing for spacing with the objective of achieving an as low as reasonably possible outcome.

- Early engagement in dialogue with stakeholders should be undertaken.

- Interested parties should avail themselves of qualified and relevant experience such that informed decisions may be made.

- Cable routing and spacing should be considered from the outset of any development planning and be incorporated into strategic risk assessments as a critical factor.

- The Facilities Design Report, Construction and Operations Plan, Fabrication and Installation Report, Site Assessment Plan and General Activities Plan should evidence that factors affecting cable spacing have been given suitable consideration.

- Subsea Cables UK has taken a leading role in Europe in terms of issues associated with submarine cables (both power and telecoms) and this has led to much cross industry understanding, project learning and coordination. It is recommended that the offshore wind industry work with the rest of the cables industry in the USA in order to consolidate, share and further develop best practice. It is also recommended that NASCA and ICPC are approached in this regard.

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Record of Changes

Rev #	Date	Description	Approved
A	2014-10-03	Initial draft for BSEE review	JDO
B	2014-12-03	Final version for RPA/PMSS America review	JDO
C			
D			
E			
F			
G			
0	2014-12-19	Final draft for client issue	JDO
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