International Energy Agency Implementing Agreement on Ocean Energy Systems

KEY FEATURES AND IDENTIFICATION OF NEEDED IMPROVEMENTS TO EXISTING INTERCONNECTION GUIDELINES FOR FACILITATING INTEGRATION OF OCEAN ENERGY PILOT PROJECTS

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FORWARD

The International Energy Agency (IEA) is an autonomous body within the framework of the Organization of Economic Co-operation and Development (OECD), which carries out a comprehensive program of energy co-operation among different countries. The Implementing Agreement on Ocean Energy Systems (IEA-OES) is one of the several IEA collaborative agreements within the renewable energy domain.

This report has been prepared under the supervision of the Operating Agent for the IEA-OES Annex III on Integration of Ocean Energy Plants into Distribution and Transmission Electrical Grids by

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It has been approved by the Executive Committee of the IEA-OES program.

This report summarises the work performed in Work Package 1 of Annex III. The work activities for this work package were led by Powertech Labs. Other contributing organisations for this report are AEA Technology of the UK, Hydraulics and Maritime Research Centre (HMRC) at the University of Cork, Ireland, Tecnalia of Spain, and AWATEA of New Zealand.

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EXECUTIVE SUMMARY

Wave and tidal current conversion technologies are advancing to the commercial stage. The conversion processes involved are highly diverse and novel, and the energy resources are variable. Several pilot projects are now connected to electrical grids, and some large-scale projects are in planning stages.

Network interconnection guidelines are essential elements to accommodate such alternative energy technologies in the more traditional marketplace. These frameworks not only accelerate the system design process, but also bring confidence amongst the network owners and operators. Development of appropriate interconnection guidelines, based on solid technical understanding of power outputs from the conversion devices and local grid constraints, will pave the path for market integration of ocean power.

Several interconnection guidelines and standards already exist for connecting generating technologies with variable power outputs, such as wind and photovoltaic (PV). Ocean energy, being a nascent field of energy engineering, can benefit significantly by adapting the technological solutions available from these industries.

The IEA-OES Executive Committee approved an Annex (Annex III) in 2007 with an overall aim: to provide a forum for information exchange and co-operative research related to the short-term and long-term integration of ocean energy into electrical systems. The Annex consisted of three work-packages and co-ordination with other relevant initiatives within IEA.

This report presents the work carried out through Work Package 1 of the Annex. It focuses on analyzing existing interconnection guidelines, codes and standards. Based on the analysis, the report identifies the areas where these guidelines could be modified to develop a suitable marine energy interconnection guideline. It is suggested that existing wind (onshore/offshore) energy standards, once revised in the marine energy context, will aid both small-scale pilot or large-scale commercial projects.

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1 INTRODUCTION

Continuous and reliable operation of a power system requires systematic co-ordination among various utilities, power producers and system operators. In addition to a number of technical requirements, such as power quality, electrical interconnection, protection and supervisory control, a set of non-technical aspects dominates the overall management of such a large system. Elements of commercial fairness, competition, cost of operation and safety are incorporated at various degrees within the network framework. In order to facilitate a mutually agreed process, interconnection guidelines, requirements or standards are generally prescribed and affect both the power producers and network authorities.

While conventional electric power from large hydro, thermal or nuclear energy sources has long been accommodated into the networks through numerous established norms, many renewable technologies require special attention in this regard. New guidelines are needed relating to resource variability, system diversity and use of relatively novel technologies (e.g., power electronics, doubly fed induction generator, etc.). Ocean energy is another emerging alternative energy field where interconnection guidelines may be needed in the short and long run. Such an initiative needs to keep sufficient balance between its present state of development and its immense future potential.

To manage the technological risks and to generate greater confidence among various stakeholders, demonstrations and short-term pilot projects will precede large-scale commercial deployment of ocean wave and tidal current devices. At present, technological advancement and general enthusiasm around the ocean energy industry have gained considerable attention[1][2]. Several landmark deployments in Europe have renewed the case of harnessing the untapped potential of the world's oceans [3][4].

The objective of this report is to review existing interconnection literature and suggest ways to aid the adoption of ocean energy (wave and tidal stream) as utility-scale pilot projects. Key aspects that form the basis of this study include:

- The scope of pilot projects as emerging technologies that may see near-term deployment
- Existing and upcoming ocean wave and tidal current technologies fit for such pilot projects
- Plant locations and use of distribution/transmission networks
- Resource variability and operational impacts on the electrical network
- Technology trends and considerations for progression into full-scale commercial farms
- Interconnection paradigms within the wind energy industry, distributed generation concepts and offshore engineering practices

Conventional bulk power generating schemes are subject to a set of rather stringent requirements, commonly known as "standards" or "codes," that aim at securing a reliable, economic and safe operation of power systems. By contrast, pilot projects could probably be accepted with more permissive criteria, typically termed "guidelines" or "best practices." Considering the level of technological maturity and the need for establishing sufficient supporting mechanisms, ocean energy technologies may deserve such an approach.

Resource variability, intermittency and predictability are significant aspects of wave and tidal energy conversion processes. While these technologies have general similarities with other renewables, such as wind or solar energy, their operation is dependent on resource variation at varying time frames and uncertainty levels. In addition, the wide diversity of operating principles of wave energy converters compared with tidal stream devices [1][2], coupled with their varying system architecture, have created equivocal perceptions among the governing authorities and energy marketers. The absence of sufficient commercial experience and lack of confidence in integrating such ocean energy systems into the electrical network could pose challenges that need to be addressed through the development of guiding mechanisms.

2 OCEAN WAVE, TIDAL CURRENT AND WIND ENERGY SYSTEMS

In order to develop an interconnection guideline suitable for ocean wave and tidal current technologies, sufficient attention needs to be given to the unique design and operational aspects attributed to such systems. While the basic electrical characteristics (such as, voltage and frequency) should ideally be in synchronism with other conventional forms of generation, these devices may require additional attention with regard to their acceptability in the grid system. Wave energy devices use the kinetic and/or potential energy of ocean waves to generate electric power, typically through a cascade of conversion processes. On the other hand, most tidal stream converters harness the kinetic energy of flowing tidewater by means of electromechanical units very similar to wind turbines. Project location, multi-unit farm operation and plant reliability (i.e., availability under normal and rough sea conditions) are several aspects that include both tidal and ocean energy devices.

In addition, resource variability and intermittency issues are common to both classes with varying degrees of time-scale and predictability. While many ocean devices are completely different from wind systems in terms of design and operation, an electric grid generally identifies all such components as of similar electrical properties. Wind energy, being one of the most mature renewable technologies, can provide insight into the existing wave and tidal stream systems and help identify subtle features of interest. In addition, existing wind-integration standards and guidelines can be enhanced or modified to accommodate ocean energy technology integration issues. Aiming to identify a set general interconnection aspects, below is an outline of technological similarities and differences between tidal and wave systems in comparison to wind energy devices:

Tidal Stream Converters

<u>Similarities</u>

- The system layout of a typical tidal device is analogous to a wind turbine, where a rotor coupled to an electrical machine transfers power via a mechanical transmission line. The grid interface (i.e., use of induction, synchronous, or power electronics) is almost identical to that of wind turbines with additional requirements for operation at sea conditions (sealing, lubrication, etc.).
- System modelling and subsequent gird connection studies pertaining to tidal stream devices can be carried out through the established concepts and norms of the wind industry. The existing knowledge base in the wind energy literature may provide significant input to such investigations.
- Tidal energy density is typically higher in narrow channels close to the shore. Therefore, a tidal plant is expected to see deployment in near-shore areas and may face design and operational constraints very similar to an offshore wind farm.

Differences

- At present most tidal current turbines are being designed and built in a modular architecture to be deployed in array configurations in the sea. This resembles the concept of wind farms employing multiple wind machines. However, wind turbines are fixed installations, whereas many tidal turbines may incorporate floating/movable structures.
- Although tidal turbines are of similar construction to wind converters, the former systems mostly operate at low rotation-high torque conditions. This requires high-ratio gearboxes or use of direct-drive generators with power electronic interfacing for grid connection at a given frequency. Depending on the design of the rotors and use of subsequent conversion techniques, the so-called "nP" frequency ripple effects may propagate into the neighbouring electrical network in the forms of flicker or fluctuations.
- The electrical collection system of the tidal plants can be laid out in various forms and this depends on factors such as site location, plant size and turbine arrangement (bottom mounted, partially submerged, or floating). Therefore, design of an offshore electrical network, fault studies and aggregated effects of multi-unit tidal farm on the power system may require a different approach for investigation than that of offshore wind farms.
- Tidal conditions can be predicted with high degree of certainty and existing measurement and forecasting facilities may meet the need for resource prediction. Also, in selected geographical locations, tidal phase mismatch may yield an averaging effect at the electrical output. These factors enhance the possibility of considering tidal plants as dispatchable units. Although for pilot projects this may not be the case, large-scale deployment would certainly require attention in this regard.

Ocean Wave Converters

Similarities

- Although the wave energy devices are significantly different in terms of front-end and intermediate conversion processes, the final stages (i.e., the grid interfacing apparatus) are very similar to wind and tidal units. In some devices, linear permanent magnet machines are being considered and this may introduce some unique issues while connecting to the grid.
- Similar to tidal plants, some wave energy conversion systems (especially shoreline and bottom-mounted nearshore devices) are expected to face technical challenges similar to those encountered in offshore wind farms. However, innovative schemes (such as Wave-Hub ™) may expose or resolve unique issues related to integration of different types of wave devices through a common terminal.

Differences

- Design of wave energy converters typically involves modular units to be placed in the ocean in an array or wave-farm. However, most wave machines are floating systems and are not permanent installations, as they are in the wind energy industry.
- The conversion processes of wave energy systems are very diverse and engage a multitude of principles of fluid mechanics and electrical/mechanical engineering. Most devices have a front-end process where any combination of heaving, pitching, or surging effects is captured. In addition, many devices operate on an intermediate scheme (pneumatic, hydraulic, open-surface air or water) that transfers power to conventional electro-mechanical units.
- The structural and operational uniqueness of wave energy devices may require new paradigms of system modelling that would suit power system studies. In addition, technology maturity and wide system diversity need to be accommodated while conducting such investigations.
- Short-term energy storage capacity inherent to many wave energy units may introduce several interesting features, such as power smoothing and equipment downsizing.
- Aggregation of multiple units into a farm would also require attention in terms of plant layout design, fault mitigation and system reliability. As wave energy density progressively increases further offshore, deep-water installation and network type (DC or AC) may contribute to factors such as reactive power and harmonics.
- Wind turbines are usually permanent installations, while offshore wave energy converters are often designed to be transported for maintenance activities. This could require intermediate electrical connectors for connection and disconnection of converters.
- Wind turbines usually include the voltage transformer for a medium-voltage connection. Some wave energy devices, due to size constraints, are not able to include the transformer and they would use a low-voltage connection.
- Ocean wave converters have the potential to generate power pulsations of high amplitude at the dominant wave frequencies. This effect may require significant energy storage and/or creative control strategies in order to mitigate the propagation of flicker into the neighboring network and to avoid breaking the network codes on voltage limits and power ramp rates.

As the technology reaches further maturity and factual information becomes available, these observations may take newer forms. At the current stage of ocean energy technologies, a grid integration guideline may attempt to accommodate some of these aspects, leaving the need for further scrutiny as an on-going process.

3 LITERATURE REVIEW AND IMPROVEMENT NEEDS

Being a nascent industry, operational experience and relevant knowledge of grid-connectivity pertaining to ocean energy technologies is limited. However, various analytic studies, observations and investigations within the realms of ocean power and in renewable energy generally have been initiated in recent times [5][6][7][8]. A comprehensive review of existing literature regarding ocean energy and its grid interconnection issues has yielded a handful of documents mostly in their draft stages [9][10][11][13]. Taking a broader approach, this search has been extended to capture insight into other areas such as:

- Wind and other generators
  - North American utility standards (BPA, FERC, BCTC, BCH)
  - European Standards (especially UK, Germany and Denmark)
  - Standards and guidelines from other organizations (IEA, AWEA, MEASNET)
- Distributed generation
  - North American context (IEEE standards, Canadian guideline)
  - Distribution network general requirement and test and protection guidelines
- Offshore engineering
  - Electrical installation design and operational codes (IEC)
  - Relevant codes by IMO

Considering the scope of an ocean energy pilot project and its possible interactions with an electrical network accepting power through a remote network, a short-list of these documents has been prepared (Table 3-1). The level of relevance is set on the basis of discussion outlined in the previous section and limitations typical to a smaller-sized project (e.g., use of distribution network, avoidance of dispatchability requirements, etc.).

Table 3-1: Existing interconnection standards and guidelines

Name	Type	Emphasis	Ref.	Rel*	Comments
Ocean Energy					
WaveNet-Thematic Network	Guideline (Draft)	Ocean Energy and Interconnection	[9]	High	– Separate interconnection and safety guideline – Considers large and commercial-scale projects in the European context
BPA-Interconnection Question	Guideline - Questionnaire (Draft)	Ocean Energy and Interconnection	[10]	High	– Important document in identifying a project's scope – Improvements needed to set the margins of acceptability for pilot projects
Powertech Labs – Accepting Criteria	Guideline - Review	Ocean Energy and Interconnection	[11]	High	– Identifies broad areas where an interconnection standard should be emphasized – Addition of questionnaire and setting the selection criteria may suffice for pilot projects
Carbon Trust-Guideline for Design and Operation	Guideline-Review	Ocean Energy and Broad issues	[12]	Med.	– Overview of design, commissioning, de-commissioning, safety, interconnection, reliability and a broad range of issues discussed.
EMEC. – Marine Energy Draft Standard	Draft Standard	Grid interface of ocean energy generators	[13]	High	– Concise draft guideline including power quality, islanding, grounding and other issues
North American – Pacific Northwest Utility Perspectives					
BPA-Transmission Interconnection	Technical Requirement	Any Generator	[14]	High	– Details the specifications for generator (conventional) connection to BPA's transmission network – Necessary guideline for other generation (e.g., wind) is given separately
BPA – Small Generator Interconnection	Standard, Agreement and Procedure	Any Generator	[15] [16]	High	– Outlines a comprehensive interconnection process for all types of generating stations – There exists a set of Large Generator Interconnection documents through BPA – May only need an annex to keep provision for ocean energy systems

Name	Type	Emphasis	Ref.	Rel*	Comments
Federal - Small Generator Interconnection	Agreement and Procedure	Any Generator	[17]	Med.	– Similar to BPA Small Generator Interconnection mechanism – There exists a set of Large Generator Interconnection documents through FERC and annexes for wind integration (LVRT and agreement process)
BC Hydro Low Voltage Interconnection	Standard	Any Generator	[18]	High	– Outlines requirements for low voltage/distribution grids – Sufficiently comprehensive and may only require an annex
BCTC	Standard	Any Generator	[19]	Med.	– Considers transmission networks and possibly large generator interconnection – Wind integration issues (LVRT, etc.) were discussed through an annex
ABB	Guideline - Draft and Review	Wind Generator	[20]	Low	– Overviews wind integration issues and progression around the world and recommends practices suitable for BC – Same approach can be taken as the ocean industry matures, restricting such method for pilot projects
Distributed Generation (DG) and Distribution systems					
IEEE Std 1547	Standard	Distributed Generator - Interconnection	[21]	High	– Developed through a comprehensive review process – Concise form of requirements (technical) may contribute significantly in developing a complete guideline
MicroPower Connect	Guideline	Distributed Generator - Interconnection	[22]	Low	– Considers distributed systems (<600V) and power electronically interfaced systems only
IEEE Std C62.41.2^{TM}-2002	Standard	Distribution Network	[23]	High	– Identifies the desired and acceptable characteristics of the distribution system for North-American grids
IEE EN 50160	Standard	Distribution Network	[24]	Low	– Similar standard for European systems

Name	Type	Emphasis	Ref.	Rel*	Comments
IEEE Std 1547.1™-2005	Standard	Distributed Generator - Test Procedure	[25]	Med.	– Test procedure complementing IEEE Std 1547
IEEE Std 1453™-2004	Standard	Test Procedure	[26]	Med.	– Flicker emission testing procedures – May become necessary for pilot projects developed in weak networks
IEEE Std. 519-1992	Standard	Test and Practice Procedure	[27]	Med.	– Harmonics emission test and mitigation procedures – Similar to flicker emission, harmonics can be a problem for power electronically interfaced ocean devices
IEEE Std C62.45™-2002	Standard	Test Procedure	[28]	Low	– Complements the IEEE Std C62.41.2™-2002 standard
IEC 62116	Standard	Protection Requirement	[29]	Low	– Power electronically interfaced (for PV system) – Islanding protection method
UL 1741	Standard	Protection Requirement	[30]	Low	– Similar islanding protection schemes for North American grids
IREC	Review	Any Distributed Generator	[31]	Low	– General overview and challenges in developing grid interconnection standards – May provide input for ocean energy systems
Wind Energy					
E.ON Offshore Wind	Requirements	Offshore Wind Park Integration	[32]	High	– Concise and relevant requirements for voltage/frequency, real/reactive power etc. – Although specified for offshore wind farms, ocean power farms (large-scale) will benefit from this document.
IEC 61400-3 Ed 1.0	Standard	Offshore Wind – Design	[33]	Low	– Design aspects of offshore wind, which may be extended/considered for offshore wave/tidal systems
IEC61400-1	Standard	Wind – Safety	[34]	Low	– Safety standards for wind turbine design may provide insight into ocean devices

Name	Type	Emphasis	Ref.	Rel*	Comments
IEC 61400-12-1	Standard	Wind – Testing	[35]	Low	– Power performance testing for wind turbines and can be used with regards to issues such as harmonics, flicker, etc.
IEC 61400-21	Standard	Wind – Power quality	[36]	Med or High	– Measurement and assessment of power quality characteristics of grid connected wind turbines, including: voltage fluctuations, current harmonics, voltage drops, active power, reactive power, grid connection, reconnection time – Proposes "test procedures" for all of these topics
IEC TS 61400-25	Standard	Wind – Communication and Control	[37]	Low	– For wave/tidal farms operating at harsh conditions a robust communication and control guideline may ensure availability and dispatchability
Offshore Engineering					
IEC 60092	Standard	Design and Operation	[38]	Low	– Electrical installations in ships
IEC 61892	Standard	Design and Operation	[39]	Low	– Electrical aspects of mobile and fixed offshore units
IMO MODU Code 1989	Standard	Design	[40]	Low	– Drilling equipment construction
IEC publication 60092-504	Review/Draft	Operation	[41]	Low	– Electrical equipment in ships and their control
* Relevance in the context of ocean energy pilot projects					

4 OUTLINE OF A GENERIC INTERCONNECTION GUIDELINE

Interconnection guidelines and standards may appear in a very generic form (such as, IEEE, IEC) or can take network-specific attributes (e.g., BPA, BCTC, BCH formats). In addition, technologies such as wind, photovoltaic or ocean energy may require a separate document or extension to an existing one. Therefore, depending on the need of the public or private utility, governing authorities and the technology in question, a guideline may reflect diverse views. An ocean energy development project may fall within the jurisdiction of a distribution or transmission system operator. This implies connection of a plant into either a low-voltage (LV) or high-voltage (HV) system. Assuming smaller projects would appear as pilot projects that would not require complete dispatachability features, the framework of operational domain can be observed through the diagram in Figure 4-1.

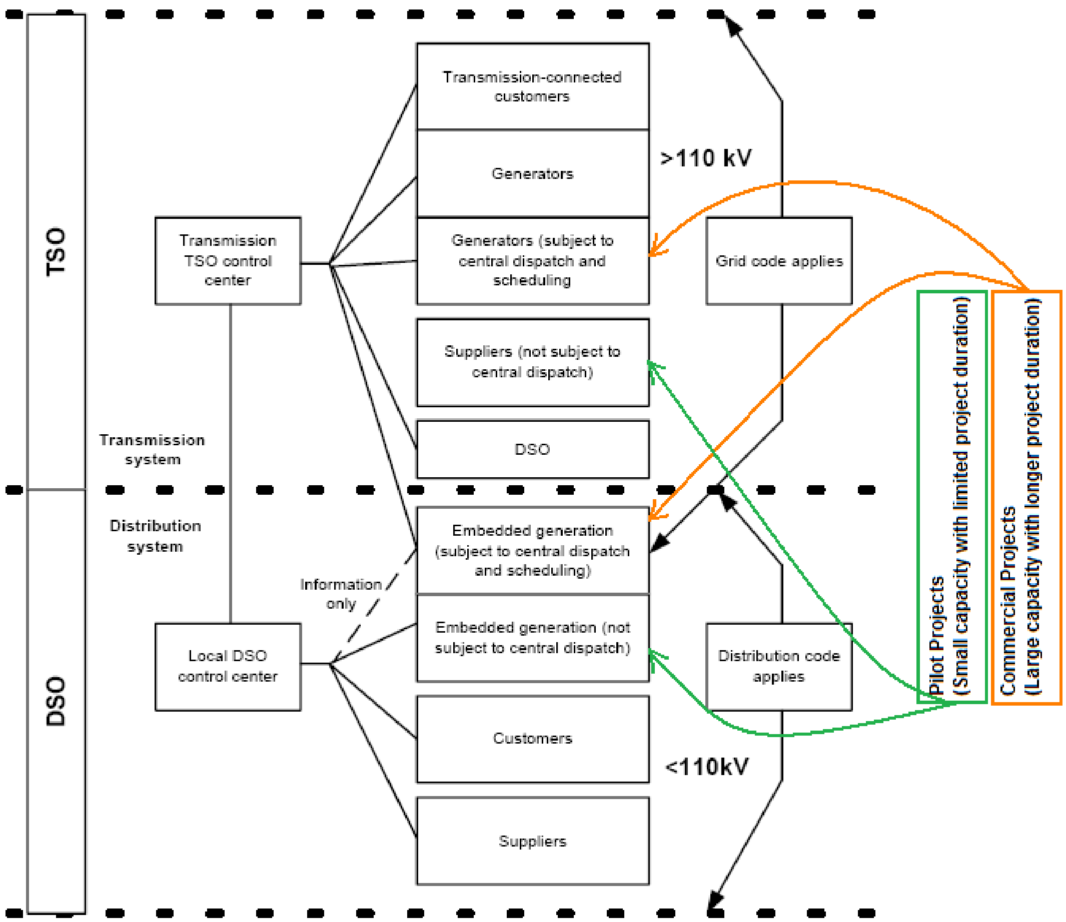

Figure 4-1: Distribution and transmission system operators' jurisdictions and project scope [9]

From planning to realisation, completing a project development cycle requires thorough understanding of the associated repercussions. Establishing a systematic approach coupled with a sufficiently comprehensive guideline is an important first step. Examples of such processes with and without having impacts on the transmission network are shown in Figure 4.2, and Figure 4.3, respectively.

The essential contents of a generic interconnection guideline are given in Table 4-1. This table lists the key elements of North American utilities grid-integration requirements. Depending on the project scope and location, a more specific set of criteria can be derived using this table.

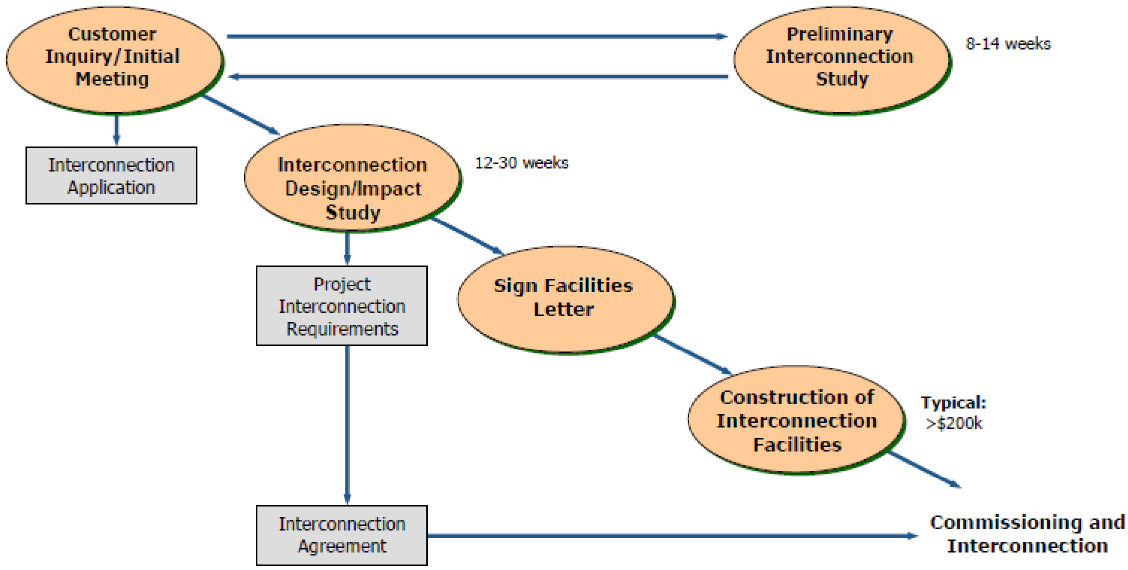

Figure 4-2: Example of interconnection process for generators with transmission impact [42]

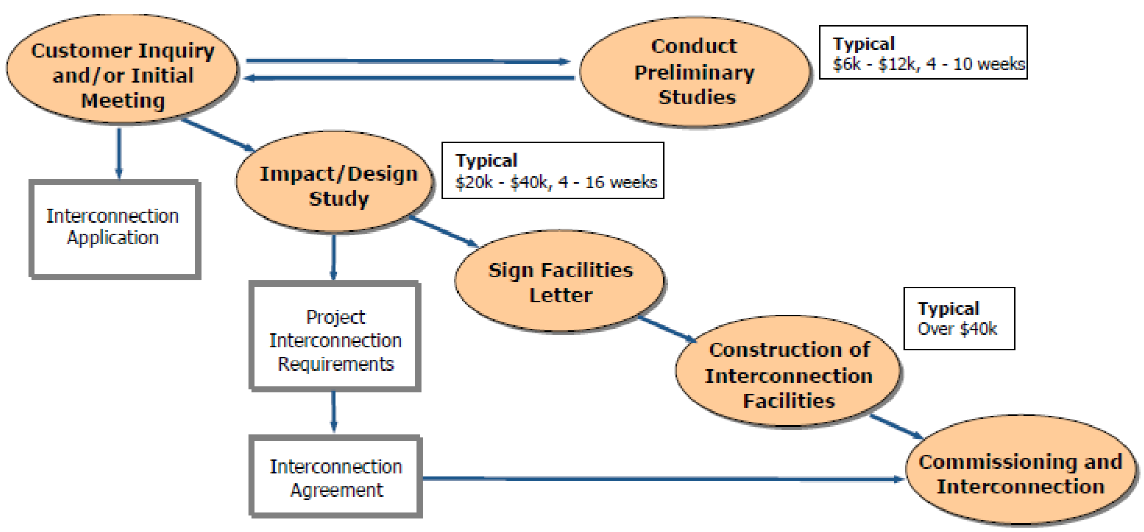

Figure 4-3: Example of interconnection process for generators without transmission impact [43]

Table 4-1: Key components of a generic interconnection guideline

Scope	Applicable Codes, Standards, Criteria and Regulations Environmental Considerations of the National Environmental Policy Act Safety, Protection and Reliability Responsibilities Special Disturbance Studies Cost Estimates
Application	Applicability Pre-Application Interconnection Request Modification of the Interconnection Request Site Control Queue Position
Interconnection Studies	Feasibility Study System Impact Study – Powerflow – Stability (Voltage, Transient, Small-signal, Frequency) – Short-circuit Facilities and Logistics Study
General Requirements	Considerations at Point of Interconnection – General Configurations and Constraints – Special Configurations and Constraints – Operating Voltage, Rotation and Frequency – Interconnection to Main Grid (Transmission) Safety and Isolating Devices Disconnect Device Requirements Transformer Considerations Transmission and Substation Facilities Insulation Coordination Substation Grounding Inspection, Test, Calibration and Maintenance Station Service and Start-up Power Isolating, Synchronizing and Blackstarting Station Service and Ancillary Services
Performance Requirements	Electrical Disturbances Requirement System Operation and Power Quality – Power Parameter Information System – Voltage Fluctuations and Flicker – Voltage and Current Harmonics – Phase Unbalance Switchgear – General – Circuit Breaker Operating Times Transformers, Shunt Reactance and Phase Shifters Generators (General Requirements) – Generator Reactive Power Requirements – Excitation Equipment Requirements – Governor Requirements – Voltage and Frequency Operation During Disturbances – Contingencies

	Asynchronous Generators Synchronous Generators. Generator Performance Testing, Monitoring and Validation Generator Blackstart Capability Power System Disturbances and Emergency Conditions Reliability and Availability Transformer Requirements Line Design Requirements (Transmission) – Conductor Size – Line Insulation – Shield Wire Line Design Requirements (Distribution) – Primary Voltage Distribution Line – Insulation – Primary Phase Conductors
Protection Requirements	Protection Criteria Protection System Selection and Co-ordination General Requirements – Sensitivity and Coordination – External Fault Detection – Equipment Rating – Unbalance and Undervoltage Entrance Protection – Protection with Relays and Circuit Breaker – Protection with Fuses and Loadbreak Switch Detection of Ground Faults – Detection of Phase Faults Requirements – Breaker Failure Protection of PG HV Circuit Breaker – Prevention of Energisation of Ungrounded Transmission Line Off-Nominal Voltage Operation Nominal Interconnection Voltage Requirements Electromagnetic Interference and Surge Withstand Off-Nominal Frequency Operation Frequency Relay Requirements Batteries / Chargers / DC Supplies DC System Requirements Line Protection Requirements (Transmission) Generator Protection – Special Requirements. Special Protection or Remedial Action Schemes Installation and Commissioning Test Requirements for Protection Systems Disturbance Monitoring
Metering and Telemetry	Telemetering Control Center Requirements Data Requirements for Control Area Services Generation and Network Interchange Scheduling Requirements Revenue and Interchange Metering System Calibration of Metering, Telemetering, and Data Facilities
Control and Telecommunication Requirements	Introduction Voice Communications Data Communications Telecommunications for Control and Protection Telecommunications During Emergency Conditions

System Operating Requirements	Generating Reserves Generation Dispatching Remote Synchronization Generation Shedding Generation Islanding Ancillary Services
Commissioning Requirements	General Commissioning Requirements Generator Commissioning Requirements Generating Unit Service Re-entry Requirements Protection Equipment Telecommunications Equipment Operating, Measurement and Control Systems Commissioning Requirements Apparatus Commissioning Requirements
Maintenance Requirements	General Maintenance Requirements Scheduled Outages Requirements Preventive Maintenance Requirements Protection and Telecommunications Equipment
Regulatory and Reliability Requirements	WECC Reliability Requirements
Contractual Agreement	Reasonable Efforts Disputes Interconnection Metering Commissioning Confidentiality Comparability Record Retention Interconnection Agreement Co-ordination with Affected Systems
Information Requirements for Generators	System Requirements Connection Location Electrical Data Commissioning Operation and Maintenance
Declaration of Compatibility	Declaration of Compatibility – Load Declaration of Compatibility – Generator (Synchronization) Declaration of Compatibility – Generator (Operating)
Other Information	Glossary of Terms Certification Codes and Standards Application, Procedures and Terms and Conditions for Interconnecting Feasibility Study Agreement System Impact Study Agreement Facilities Study Agreement

5 OUTLINE OF A OCEAN ENERGY INTERCONNECTION GUIDELINE

With limited experience of ocean energy devices in grid-connected mode of operation, it is both impractical and inappropriate to set strict requirements. However, using the perceived knowledge from the wind energy sector and integrating various unique aspects of ocean wave and tidal stream conversion processes, the following table has been generated. While this list only serves the purpose of identifying several areas of interest, further investigation needs to be carried out in quantifying the ranges of these possible requirements.

A guideline for ocean energy systems may appear in the form of a separate document or as an annex to an existing standard. For the North American region, similar approaches can be taken using available interconnection requirements adapted for the specific issues associated with ocean wave or tidal stream energy, as indicated in Table 5-1. Depending on the nature of the project (pilot or full-commercial, distribution or transmission system connection), the content of the guideline can be adjusted using the flow-chart shown in **Error! Reference source not found.**. At present, any such document would inherently contain elements of uncertainty and issues of contradiction. With further technological advancement and accumulation of practical experience, these guidelines can be re-evaluated and modified for more comprehensive recommendations.

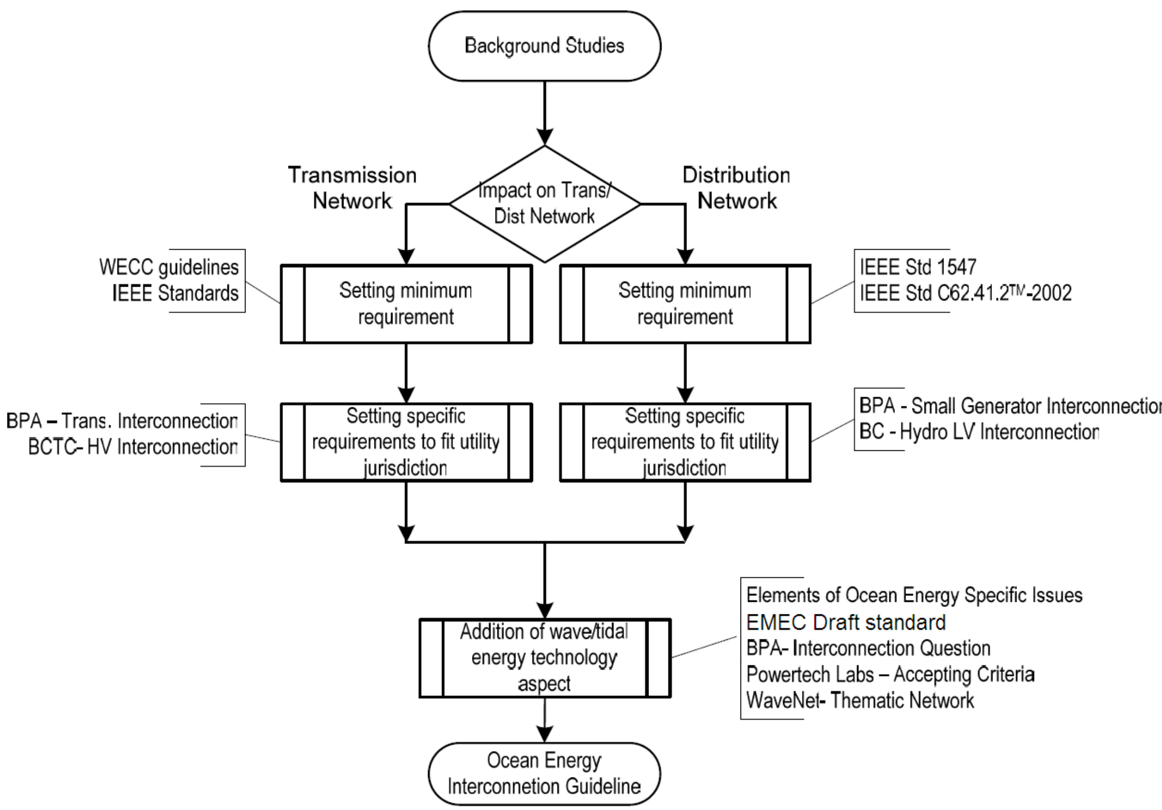

Figure 5-1: Example of a flow-chart for ocean energy interconnection guideline development for west coasts of North America

Table 5-1: Possible ocean energy system interconnection requirement issues [10]

Technology Type	Ocean Wave or Tidal Current Device Classification Conversion Process (Front End, Intermediate, Final) Device Location (Shore-line, Near-shore, Offshore) Plant layout and Connection Diagram Single Unit or Multi-Unit System Generator type and Common Interconnection Points Transformer Location
Operational Requirements	Low Voltage Ride Through (LVRT) Reactive Power Frequency control Dispatchability
Generator Units to Shoreline Interface	Submarine Cable Conductor Short Overhead Cable Connection to Close-In Unit Floating Cable Connection Distance From Generator to Shore-Line Interface Voltage Rating Voltage Rating vs. Ampacity Conductor Size vs. Loading/Generation Block Size Double-Ended/Looped vs. Single-Ended/Radial Line Maintenance Voltage Drop And Losses
Shoreline Interface – Simple Conductor Inter-Connect	Underground Vault Splices – Continued Underground Pole-Top Cable Potheads – Continued Overhead Open-Wire Pole-Top Cable Potheads – Continued Overhead Spacer Cable Disconnecting Means at Shoreline Interface
Shoreline Interface – Circuit Breaker/Fuse	Pole-Mounted Fused Disconnect Pole-Mounted 3-Phase Automatic Circuit Recloser Pad-Mounted Fused Disconnect Pad-Mounted 3-Phase Automatic Circuit Recloser Remote Indication of Breaker Trip/Blown Fuse
Shoreline Interface – Step-Up Transformer	Simple Pad-Mounted Transformer with Fuse Protection Existing Substation Near Shoreline Interface New Substation, Complete with Transformer Equipment – Basic Transformer And Line Protection – Required Protective Relaying – Remote Indication of Outages – Real-Time Data Telemetry – kWh Metering with Remote Query for Data – SCADA Control and Remote Indication New Substation Tie to Grid Primary Voltage Line – Maintenance – Single-Ended Radial Tie – Double-Ended Looped Tie – Redundant Transformers – Breaker-And-A-Half Or Ring-Bus Configuration

Shoreline Interface to Grid/Subgrid Interconnection	Voltage Level Voltage Rating vs. Ampacity Conductor Size vs. Loading/Generation Block Size Double-Ended/Looped vs. Single-Ended/Radial Voltage Drop and Losses Existing Network and Load New Network
Interconnection - Dedicated Line(s) To Substation	Existing Substation with Upgrades and Additions – Transformer and Line Protection – Required Protective Relaying – Remote Indication of Outages – Real-Time Data Telemetry – kWh Metering with Remote Query for Data – SCADA Control and Remote Indication New Substation Complete with Transformer Equipment – Basic Transformer and Line Protection – Required Protective Relaying – Remote Indication of Outages – Real-Time Data Telemetry – kWh Metering With Remote Query For Data

6 SUMMARY: PILOT PROJECT GUIDELINES

Being an emerging technology, a pilot project in the ocean energy sector is expected to employ marginally proven schemes and methods. Considering the current state of this technology, it is reasonable to assume that the project size would be in the range of 100 kW to 10 MW. While some developers envision limited power generation for isolated communities, most are expecting to graduate into larger full-scale commercial projects in the long run. Therefore, a pilot ocean energy project guideline detailing the grid interconnection requirements may encompass the following aspects:

- Developing a streamlined guideline where both the project developer and the utility can work in a coordinated manner
- Providing sufficient flexibility to accommodate ocean technology as a young and unproven solution
- Maintaining adequate measures to contain the risks of integrating such devices, from the utility perspective
- Encouraging self-imposed certification processes by the project developers
- Allowing the process of knowledge transfer such that a comprehensive long-term standard may reflect the experience gained from smaller projects

REFERENCES

[1] U.S. Department of Energy, Marine and Hydrokinetic Technology Database, [Online, Accessed on March 09]. Available: http://www1.eere.energy.gov/windandhydro/hydrokinetic/default.aspx

[2] M.J.Khan, G. Bhuyan, A. Moshref, K. Morison, An Assessment of Variable Characteristics of the Pacific Northwest Region's Wave and Tidal Current Power Resources, and their Interaction with Electricity Demand & Implications for Large Scale Development Scenarios for the Region, Powertech Labs Inc. report No.17845-21-00 (REP 3). [Online, Accessed on March 09]. Available: http://www.powertechlabs.com/cfm/index.cfm?It=106&Id=58

[3] PelamisWave Power Ltd., Press Release. (2008, 23 Sept.); World's First Commercial Wave Power Project goes live; [Online]. Available: http://www.pelamiswave.com/news.php?id=26

[4] Marine Current Turbines Ltd., Press Release (2008, 17 Nov.); SeaGen Enters Final Stage of Commissioning, [Online]; Available: http://www.marineturbines.com/3/news

[5] Econnect Consulting, Ocean Energy Conversion Expert Group, Report from Meeting in Vancouver, April 2006, project No: 1698.

[6] Anna Estanqueiro, "Grid Integration on Ocean Energy Systems, Integration of Ocean Power Systems in the Grid: The Experience from Other REs," IEA-OES Meeting, Copenhagen, Denmark, November 2004.

[7] Polinder, H., Scuotto, M., "Wave Energy Converters and their Impact on Power Systems," in International Conference on Future Power Systems, Nov. 2005.

[8] Satoshi Morozumi, NEDO Research Related to Battery Storage Applications for Integration of Renewable Energy, New Energy and Industrial Technology Development Organization (NEDO), [Online, Accessed March 09], Available: http://www.sandia.gov/regis/presentations/S_Morozumi-NEDO.pdf

[9] WaveNet, "Results from the work of the European Thematic Network on Wave Energy, European Community, Tech. Rep. ERK5-CT-1999-20001, 2000-2003, URL: http://www.oreg.ca/docs/WaveNet%20Full%20Report(11.1).pdf.

[10] John Schaad, "Interconnection Questions – Wave and Tidal Energy Projects (Draft), Bonneville Power Administration," Customer Service Planning & Engineering, 86000 Highway 99S, Eugene, OR 97405, Jan 2008, ver. 1.06 (Draft).

[11] Powertech Labs Inc., "Acceptance Criteria for Wave Generated Power," BC Hydro Project, Tech. Rep. Project 14118-32, Report 14118-02-REP1.

[12] The Carbon Trust, Guidelines on design and operation of wave energy converters: A guide to assessment and application of engineering standards and recommended practices for wave energy conversion devices, May 2005.

[13] EMEC, A (draft) standard for The Grid Interface of Marine Electrical Generator Installations, [Online], Available: http://www.emec.org.uk/national_standards.asp

[14] BPA, "Bonneville Power Administration Technical Requirements for Interconnection to the BPA Transmission Grid," June 15 2005, REVISION 0.

[15] ——, Small Generation Interconnection 20-MW BPA Transmission; FERC Order 2006 Small: Generation Interconnection Procedure (SGIP). [Online, Accessed on March 09]. Available: http://www.transmission.bpa.gov/business/generation_interconnection/

[16] ——, Small Generation Interconnection 20 MW BPA Transmission; FERC Order 2006 Small: Generation Interconnection Agreement (SGIA). [Online, Accessed on March 09]. Available: http://www.transmission.bpa.gov/business/generation_interconnection/

[17] ——, FERC, Small Generator Interconnection Agreement (SGIA)-(For Generating Facilities No Larger Than 20 MW). [Online, Accessed on March 09]. Available: http://www.ferc.gov/industries/electric/indus-act/gi/small-gen/procedures.doc

[18] BC Hydro, "35 kV and Below, Interconnection Requirements For Power Generators," Nov. 2006.

[19] British Columbia Transmission Corporation (BCTC), "69 kV to 500 kV, Interconnection Requirements for Power Generators," December 2006.

[20] ABB, “Wind Farm Integration in British Columbia,” Mar. 2005, report: 2005-10988-2.RO1.3, 2005-10988-2.RO2.2.
[21] IEEE, “IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.”
[22] Canmet Energy, “MicroPower Connect Interconnection Guideline: For inverter based micro-distributed resource (DR) systems connected to 600 volt or less distribution systems,” 2003, v8.
[23] ——, “IEEE Std C62.41.2TM-2002, IEEE Recommended Practice on Characterization of Surges in Low Voltage (1000 V and less) AC Power Circuits.”
[24] IEE, “IEE EN 50160, Voltage Characteristics in Public Distribution Systems Voltage Disturbances.”
[25] IEEE, “IEEE Std 1547.1-2005, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.”
[26] ——, “IEEE Std 1453-2004, IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems.”
[27] ——, “IEEE Std. 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.”
[28] ——, “IEEE Std C62.45TM-2002, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000V and Less) AC Power Circuits.”
[29] IEC, “IEC 62116, Testing Procedure of Islanding Prevention Measures for Utility Interactive Photovoltaic Inverters.”
[30] ——, “UL 1741, Static Inverters and Change Controllers for Use in Photovoltaic Power Systems.”
[31] IREC, “IREC-Connecting to the Grid: A Guide to Distributed Generation Interconnection Issues,” 2007, 5 E/d.
[32] E.ON Netz GmbH, Requirements for Offshore Grid Connections in the E.ON Netz, April 01, 2008, [Online], Available: http://www.eon-netz.com/pages/ene_de/Veroeffentlichungen/Netzanschluss/Netzanschlussregeln/080702ENENAROS2008eng.pdf
[33] IEC, “IEC 61400-3 Ed 1.0 Wind turbines - Part 3: Design Requirements for offshore wind turbines.”
[34] ——, “IEC61400-1 Wind Turbine Generator Systems Part 1: Safety Requirements.”
[35] ——, “IEC 61400-12-1 Wind Turbines - Part12-1: Power Performance Measurements of Electricity Producing Wind Turbines.”
[36] ——, “IEC 61400-21 Ed 2.0: Wind turbines - Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines”
[37] ——, “IEC TS 61400-25 Ed 1.0 Wind turbine generator systems Part 25-1 to -6: Communications for monitoring and control of wind power plants.”
[38] ——, “IEC 60092 Electrical installations in ships.”
[39] ——, “IEC 61892 Mobile and fixed offshore units Electrical installations.”
[40] IMO, “IMO MODU Code 1989 International Maritime Organization - Offshore; Code for Construction and Equipment of Mobile Offshore Drilling Units.”
[41] IEC, “IEC publication 60092-504,” Electrical installations in ships, part 504: Special features, control and instrumentation”.”
[42] BC Hydro, Distribution Generator Interconnection (35 KV or Less), [Online, Accessed on March 09], Available: http://www.bchydro.com/etc/medialib/internet/documents/planning_regulatory/acquiring_power/d_interconnection_cpc.Par.0001.File.d_interconnection_cpc_sept_18.pdf
[43] BC Hydro, Distribution Connected Generator Interconnection, [Online, Accessed on March 09], Available: http://www.bchydro.com/etc/medialib/internet/documents/info/pdf/info_generator_interconnections_flowchart_without_transm.Par.0001.File.info_generator_interconnections_flowchart_without_transm.pdf