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A review of combined wave and offshore wind energy

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ABSTRACT

The sustainable development of the offshore wind and wave energy sectors requires optimising the exploitation of the resources, and it is in relation to this and the shared challenge for both industries to reduce their costs that the option of integrating offshore wind and wave energy arose during the past decade. The relevant aspects of this integration are addressed in this work: the synergies between offshore wind and wave energy, the different options for combining wave and offshore wind energy, and the technological aspects. Because of the novelty of combined wave and offshore wind systems, a comprehensive classification was lacking. This is presented in this work based on the degree of integration between the technologies, and the type of substructure. This classification forms the basis for the review of the different concepts. This review is complemented with specific sections on the state of the art of two particularly challenging aspects, namely the substructures and the wave energy conversion.

Contents

Abbreviations: GBS, gravity based substructures; MRE, marine renewable energy; NDA, non-uniformly distributed array; O&M, operation and maintenance; ORE, offshore renewable energy; PDA, peripherally distributed array; SET-Plan, strategic energy technology plan; TRL, technology readiness level; UDA, uniformly distributed array

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1. Introduction

Offshore renewable energy (ORE), which includes both ocean energy and offshore wind, has a great potential for development [1,2] and is called to play a fundamental role in the EU energy policy, as identified by, e.g., the European Strategic Energy Technology Plan (SET-Plan). The industry has established, as a target for 2050, an installed capacity of 188 GW and 460 GW for ocean energy (wave and tidal) and offshore wind, respectively [3–5]. Given that the target for 2020 is 3.6 GW and 40 GW, respectively [6], it is clear that a very substantial increase must be achieved if the 2050 target is to be realised, in particular in the case of ocean energy.

Offshore wind energy is defined as the energy generated from the wind at sea, and ocean energy as the energy present in oceans and other water bodies in the form of: waves, marine currents, tides, ocean thermal energy gradients or salinity gradients. Sharing the same hostile marine environment, ORE industries face similar challenges, yet their level of technological development is not the same. Whereas offshore wind is a proven technology, with 3.8 GW of installed capacity in Europe and employing 35,000 people directly and indirectly at the end of 2011 [5,7], ocean energies are still at an early stage of development.

The sustainable development of offshore wind and ocean energy requires an efficient use of the natural resources, i.e., one that optimises their exploitation. It is in relation to this and the challenge, common to both industries, to reduce costs that the incentive for integration arises. Within ocean energy this review is restricted to wave energy, for the other ocean energy technologies either are at present less developed either the combined resource is scarce and hence present fewer opportunities for integration with offshore wind.

The combined exploitation of wave and offshore wind energies is a very recent research topic, a limited number of papers draw on the combination of wave and offshore wind energy being these mostly focused on the resource assessment and potential of a combined wave–wind energy extraction [8–12] or the grid integration issues of a combined electric production [13,14]. Some seminal publications which are mainly focused on either the combined electricity production (from the point of view of grid management) [15–21], either the proposal of new alternatives to combine the exploitation of wave–wind energies (i.e., energy islands or hybrid wave–wind energy converters) [22–26] or looking into the different synergies between both energies and its implications [27]. Nevertheless, most of the work carried on in the last few years on combined wave–wind energy has been done by some EU funded research projects [28–32] which try to enhance the industrial and scientific collaboration to develop a more sustainable energy. As an output of these projects some research or public reports have tackled the combination of wave and offshore wind energy [4,33–35], focusing on the combined resource, the synergies between different OREs and the technical requirements of a hybrid platform. Apart from these specific studies, there have not been any publications that present a general view of the different combined wave and offshore wind possibilities, including those making use of the bottom-fixed offshore wind technology which is currently of commercial interest [36,37].

The objective of the present paper is to review the different alternatives for combining wave and offshore wind energy, to give a complete view of the possibilities and current limitations of these systems. It is structured as follows: In Section 2 the combined wave–wind resource is analysed, with special attention to the European possibilities. Section 3 outlines the synergies between both energies. The various options are classified and examined in Section 4. The two main aspects from the technological point of view, the substructures and the wave energy conversion technologies, are reviewed in Sections 5 and 6, respectively. Section 7 looks into the technology development issues which of combined wave–wind systems. The economics of combined systems is outlined in Section 8. Finally, conclusions are drawn in Section 9.

2. The resource

OREs, and especially offshore wind and waves, are amongst the renewables with the greatest potential. In the European coasts the available energy power is about: 350 GW for wind and 320 GW for waves (considering the NE Atlantic and Mediterranean). This represents the 50% for Wind, 46% waves and the remaining 4% for tidal [1,3,4]. Nevertheless, is at the North Atlantic costs and at the North Sea, where Europe's has its strongest and more valuable wind and wave energy resources.

The best wave conditions for exploitation as an energy resource are found in medium-high latitudes and on deep waters (more than 40 m), reaching power densities of 60–70 kW/m. Moreover, about 2% of the world's 800,000 km of coastline exceed a power density of 30 kW/m, with a technical potential of about 500 GW based on a conversion efficiency of 40%. The total European wave