Renewable Energy 97 (2016) 866–880

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Cost assessment methodology for combined wind and wave floating offshore renewable energy systems

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A R T I C L E I N F O

Article history:
Received 10 December 2015
Received in revised form
4 June 2016
Accepted 6 June 2016
Available online 29 June 2016

Keywords:
Marine renewable energy
Hybrid systems
Cost
LCOE
Wave energy
Offshore wind energy

A B S T R A C T

A methodology is presented to assess the life-cycle costs of combined or hybrid floating offshore renewable energy systems, which is also applicable to general floating offshore renewable energy devices. It accounts explicitly for their life-cycle stages: concept definition, design and development, manufacturing, installation, exploitation and dismantling. It is a tool for decision-making and strategic planning, enabling a better understanding of the technological solutions and the aspects that might accelerate or decelerate the development of the industry. The method presented can be useful for comparing different types of floating offshore hybrid renewable energy technologies in terms of costs. The general methodology has been applied for the particular case of two specific hybrid systems: the W2Power and the Poseidon. Results for two locations in Portugal (São Pedro de Moel and Aguçadoura) indicate that the exploitation, manufacturing and the installation costs are the most important ones, with the exploitation cost being the most important for the W2Power and the manufacturing cost being the most important for the Poseidon. The Levelized Cost Of Energy is lower in São Pedro de Moel but when considering the technology the W2Power has lower Levelized Cost Of Energy in the single unit scenarios and the Poseidon in the farm scenarios.

1. Introduction

Ocean energy is one source of renewable energy that can be exploited from waves, tides, tidal currents, thermal gradients or salinity gradients. In the ocean energy industry, the wave energy sector has been focused on the exploitation of the resource and production of useful energy (i.e. electricity) through the development of appropriate technology. Several concepts have been developed so far with no particular preference between the alternatives, most at an early stage of development [1]. Falcão [2] and Guedes Soares et al. [3,4] described and classified these different concepts designed to extract energy from waves. They are classified in floating [5] or fixed systems located onshore, near shore or offshore. This paper is focused on floating offshore concepts.

Wind energy is another source of offshore renewable energy [6]. Wind resources tend to be better at distances from shore, as the wind is stronger and with less irregular behaviour [5,6,9]. The majority of the concepts of offshore wind technology consist of horizontal-axis turbines, which are similar to onshore wind devices. Foundations are a critical element in the deployment of these devices. The selection of a given type of foundation and design depends on aspects such as sea floor geology, water depth or sea state conditions. Floating foundations are designed for deep waters but are still at an early stage of development. Spars, tension leg platforms (TLP) and semisubmersible are some of the main concepts for these types of foundations, considering the type of floating platform in which the device is supported [6–8].

This work is focused on floating offshore concepts based on wave and wind converters [10]. Wave devices are designed to be deployed in locations with a particular set of characteristics hence the variety of solutins, which will adapt to different conditions, have different operational ranges and have different efficiencies depending on the sea state [11]. Likewise, wind devices extract power with a given efficiency within an operating range of wind

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http://dx.doi.org/10.1016/j.renene.2016.06.016
0960-1481/

speed [12,13]. Performance might also be affected by wake effects on neighbouring turbines. In addition, as these devices are located away from the coast they might exploit higher power levels but at the cost of survivability or accessibility issues due to harsher sea state and weather conditions [6,14]. Therefore, while the attractiveness of a region might be quantified by its power levels it is ultimately dependent on an adequate match between device and location. These aspects demonstrate that knowledge about resource characteristics in a potential location is of great importance. Resource assessments are meant to provide this knowledge, with possible options being in-situ measurements or numerical modelling techniques [15–18].

The main aspects that should be taken into account in a project are concept and location. Projects, from the beginning to the end, comprise a set of operations and costs over time, and these determine their feasibility. Project costs are associated with the resources, infrastructures and deliveries required along the life cycle. These costs are either capital costs (CAPEX) or operating costs (OPEX) [20,21]. Costs are site-specific and depend on aspects such as geographic conditions, technical design or market conditions [7,21].

Wave energy technology is beginning its development, with a reduced number of full scale grid connected projects [2]. Limited experience hampers the assessment of project feasibility in the industry with an adequate level of confidence due to the current lack of data and high number and degree of uncertainties [19]. These projects are capital intensive and entail significant risk for investors. Offshore wind projects are also capital intensive, and although there are some grid connected projects deployed it is still a young industry sector [21].

Systems for combined extraction of renewable energy are an option that is being considered recently. The combined extraction enables the efficient use of the offshore resources and possible cost reductions – in absolute or relative terms – due to synergies such as increased energy yield, shared logistics and maintenance activities or common substructure. These systems have been classified and reviewed by Pérez-Collazo et al. [22] and Karmakar and Guedes Soares [23] as co-located, hybrid or island.

Co-located systems comprise wave and wind devices that either (1) share the same ocean area and part of the infrastructure (e.g. grid) – forming combined arrays, which can be peripherally, uniformly or non-uniformly distributed, or (2) are placed independently in different ocean areas but close enough to share the grid connection system and other operations – forming independent arrays. Hybrid systems are bottom-fixed or floating devices that combine offshore wind energy and wave energy conversion on the same structure. These systems might serve other purposes, being part of the offshore structures considerable as multiuse platforms. Island systems are also a type of multiuse platforms that usually combined more than two types of energy sources on the same structure and are larger than hybrid systems. Nowadays, co-located, hybrid and island models are being developed, therefore their level of maturity is improving day by day.

The potential benefits of these systems are several but at such an early stage of development it is difficult to assess any scenario in terms of its total cost or economic feasibility. Moreover, current studies in the literature do not address the economic feasibility of these systems or how to estimate it.

Levelized Cost Of Energy (LCOE) can be calculated from two main perspectives: the society and the developer [22]. In the context of offshore wind, there are authors that determined the LCOE of several floating offshore wind platforms: spar-buoy (Hywind II), Tension-Leg-Spar (Sway), Semi-submersible (WindFloat), Tension-Leg-Wind-Turbine (TLWT) and Tension-Leg-Buoy (TLB), considering their life cycle analysis [23]. They have results from 82 to 236.7 €/MWh for the LCOE. Others take into account only the maintenance cost [24]. On the other hand, other papers compare bottom-fixed offshore wind structures and floating offshore platforms [25], with values of LCOE of 134.7 €/MWh and 150 €/MWh respectively.

This paper presents a methodology to assess the life-cycle costs of floating offshore combined or hybrid renewable energy systems that is also applicable to a general floating offshore renewable energy device. It considers the location characteristics [26], the technical requirements, costs and external conditions to determine the economic feasibility and its most relevant characteristics. The methodology is a tool for cost estimation but also decision-making and strategic planning, enabling a better understanding of the technological solutions and aspects that might accelerate or decelerate the development of the industry.

The general methodology proposed has been applied to a particular case of two specific floating offshore hybrid systems: the W2Power and the Poseidon. These are considered for two different locations in Portugal (São Pedro de Moel and Aguçadoura) in two different scales – single unit and farm.

The paper proceeds as follows. First the methodology is introduced. Then the case study is presented, considering the different technologies, location characteristics and scenarios. This is followed by the presentation of the results in the next section. Conclusions are addressed in the last section.

2. Methodology

2.1. General view

The methodology proposed has been adapted from floating offshore wind [24] and wave technology method [25] and it is based on the life-cycle of floating offshore renewable energy devices, composed by six main stages (see Fig. 1): concept definition, design and development, manufacturing, installation, exploitation and dismantling.

The costs in each of these stages comprise the Life-cycle Cost System (LCS) of a hybrid floating offshore renewable energy farm (HFOREF), as follows:

$$LCS_{\mathrm{HFOREF}} = C1 + C2 + C3 + C4 + C5 + C6 \quad (1)$$

being:

- C1: cost of concept definition.
- C2: cost of design and development.
- C3: cost of manufacturing.
- C4: cost of installing.
- C5: cost of exploiting.
- C6: cost of dismantling.

These costs have been studied to develop the method to calculate the total cost, in €, and the LCOE, in €/MWh, of floating offshore renewable energy devices, as a function of a set of parameters. Most parameters can be obtained through actual research or can be estimated based on literature information, expert consultation or data related to projects with relevant similarities.

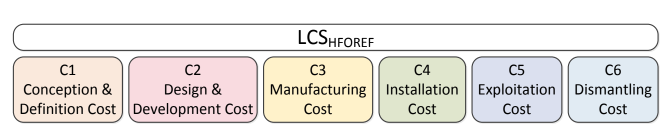

Fig. 1. General view of the methodology proposed.