International Journal of Marine Energy 18 (2017) 15–29

Contents lists available at ScienceDirect

International Journal of Marine Energy

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

Towards a cost-based design of heaving point absorbers

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ARTICLE INFO

Article history:
Received 8 November 2016
Revised 22 February 2017
Accepted 27 March 2017
Available online 31 March 2017

Keywords:
Heaving point absorber
Phase control
Hydrodynamic optimization
Levelised Cost of Energy
Annual Energy Production per unit area

ABSTRACT

The need for increasing the share of sea resources in the global renewable energy market requires a specialized design of wave energy converters and Power Take-Off units that, in turn, may be capable of maximising power production and minimizing extraction costs. In this respect, as optimization of wave energy converter performances, by properly tuning relevant hydrodynamic parameters and controlling the motion in waves, reveals a basic issue to reduce energy production charges, a new cost-based design procedure for heaving point absorber type devices is developed, with the main aim of accounting for wave climate at deployment site, reliable device operational profiles and design restraint criteria for both floating buoy and Power Take-Off unit. The newly proposed cost-based procedure is applied to detect the optimum configuration of heaving point absorber devices at several candidate deployment sites. Finally, the incidence of wave climate and available energy resources, on detecting the optimum device configuration and assessing relevant energy production costs, is investigated and fully discussed.

1. Introduction

Interest in power generation from waves has increased since the oil crisis of the 1970s, mainly due to the rapid growth of oil prices and climate change threats that induced a major change in renewable energy scenarios and raised the interest in large-scale energy production from waves [27]. In this respect, since the milestone work by Salter [52], a variety of wave energy conversion systems has been developed by the international scientific community, thanks to several research and development programs, initially funded by British and Norwegian Governments, with the construction in 1985 of the first fully-sized shoreline prototypes near Bergen. In the following years, most of research activities remained at a theoretical level, until the European Commission included, in the early 1990s, wave resources into the common framework on renewable energies and the International Energy Agency established the first Agreement on Ocean Energy Systems, to support research through international co-operations and information exchanges. Following the growing interest in harnessing wave energy, a variety of theoretical works on hydrodynamics of wave energy converters ([56,28,57,47], among others) and technical reports ([51,54] among others), providing invaluable information about state-of-art and the most promising technologies, have been provided by researchers and international institutions. In the same years, several efforts were also undertaken to design Power Take-Off units capable of efficiently converting mechanical into electrical power and properly controlling the device motion, to increase relevant performances in harsh weather conditions and decrease wave energy

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http://dx.doi.org/10.1016/j.ijome.2017.03.005
2214-1669/

extraction costs, generally higher than other renewable resources, such as solar and wind among others, due to more challenging installation and maintenance issues. In this respect, during the last decade several cost reduction opportunities, mainly arising from the increase of manufacturing and installation experience, were investigated, as wave energy technology is still in a pre-commercial phase that is characterized by high uncertainty levels and not totally reliable cost projections [39]. Hence, as for other renewable resources [7–9], optimization of wave device hydrodynamic performances became a popular topic, as shown by the growing interest in increasing the device efficiency and properly tuning relevant natural period, by means of different motion control strategies [56,26,20,4,63,48], devoted to put the device at near-resonance conditions. Anyway, all efforts, devoted to optimize WEC device performances, by properly controlling relevant motion in waves, were mainly based on some chosen sea states, representative of prevailing climate at deployment site, eventually combined with some design restraint criteria, to avoid unrealistic design configurations. In this respect, following the need for a more comprehensive assessment of WEC device performances, three main subjects are fully investigated, with reference to heaving point absorber type devices:

(i) A comprehensive new cost-based procedure, devoted to optimize the hydrodynamic performances of heaving point absorbers, is developed, accounting for all sea states representative of deployment site probabilistic wave climate and reliable design restraint criteria for both wave energy converter and Power Take-Off unit, with the main aim of detecting the optimum design characterized by minimum wave energy production costs, based on reliable operational profiles.
(ii) The incidence of wave climate on detecting the optimum wave device configuration is investigated, based on several candidate deployment sites, chosen as case studies for the newly developed procedure.
(iii) A comparative analysis among energy production costs at different deployment sites is performed, to investigate the incidence of wave frequency spreading on optimal tuning of device hydrodynamic parameters.

Actual efforts, mainly devoted to make wave energy production more attractive and competitive than other renewable sources, are undertaken to comply with well-known European Council targets for renewable energies, to be achieved within 2020, with reference to: 20% share of renewable energy in the European Union; 20% reduction of greenhouse gas emissions, compared to the values of 1990, and 20% increase in energy efficiency.

2. Basic principles of wave energy extraction

2.1. Review of main WEC typologies

Various examples of WEC devices, designed to extract energy from waves and based on single or combined surge, heave or sway motions, were proposed and investigated in the last two decades. In this respect, WEC devices are generally classified into several categories, depending on wave energy extraction methods [54]. Attenuators [49] convert wave energy into electricity, thanks to the oscillatory motion between two or more adjacent floating bodies that, in turn, activate the cylinders of a hydraulic plant or are directly coupled to a Power Take-Off system. Point absorbers [13,58] are mainly based on the relative heave motion of a floating buoy, as regards a fixed structure, moored on the seabed or held in place by its own weight, through a large foundation mass. Oscillating wave surge converters [62,61] harness the wave particle motion that, in turn, moves the device as a pendulum mounted on a pivoted joint, so activating the energy conversion system. Oscillating water column devices [25,3], generally located at near-shore sites as bottom fixed structures, mainly consist of a chamber, partly filled by water. Variations of wave height let the water to rise and fill in the chamber, acting as a large piston and activating an air turbine, provided with a flow reversal system and producing electricity when water level rises or falls. Overtopping or terminator devices [43,37] convert wave energy into electricity, capturing waves into a reservoir, located above the free water surface, that subsequently flow through a low-head hydraulic turbine. Finally, pressure differential devices [38], in floating or fully submerged modes, experience heave motions as waves pass over them, causing a temporary vertical force on the body, which activates an air turbine. Hence, based on current review of main WEC typologies, point absorbers are selected as they represent ones of the most promising technologies, with the main aim of establishing a rational cost-based procedure, devoted to maximize wave energy extraction and minimize relevant production costs.

2.2. Power Take-Off systems

Conversion of wave energy into electricity is generally performed by means of linear or high-speed rotary electrical generators, the last ones driven by an air turbine or a hydraulic motor [46,23]. Currently, the most popular choice for heaving point absorbers is a Power Take-Off (PTO) system, utilizing hydraulic components as first conversion step and coupled with a rotating electrical generator, so providing two main functionalities, the former related to motion control and optimization of energy transferred from incident waves to WEC device, the latter devoted to conversion of mechanical to grid compliant electrical power [6]. In this respect, hydraulic PTOs may be classified into variable and constant pressure systems [50] even if in both cases, the first conversion step is always provided by one or several hydraulic cylinders, connected to the point absorber and extracting power from relevant heave motion. Particularly, in variable pressure PTO systems hydraulic