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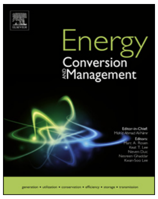

A reliable open-source package for performance evaluation of floating renewable energy systems in coastal and offshore regions

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ABSTRACT

The booming developments of coastal/offshore renewable energies in recent years call for a powerful numerical code, ideally open-source packaged, to accelerate the researches in the spotlight. This paper presents such an efficient software package for evaluating the performance of floating renewable energy systems in the coastal and offshore regions. It aims to contribute an open-source effort in numerical simulations for ocean energy converters. Though computation of the free-surface effect in moderate depth region is extremely troublesome due to the singularities, the software package proposed in the present paper gives a satisfactory solution to keep the balance of accuracy and efficiency. In the present paper, the interface and structure of the package are introduced in detail so as to be well understood by the reader. Benchmark tests for various types of converters have confirmed the accuracy and efficiency of the package which can be incorporated easily with a frequency domain solver for efficient analysis. By contributing as one of the pioneer works in the open-source effort of evaluating the moderate-depth free-surface Green's function, with its advantages of a reliable accuracy and a relatively low cost, the authors are hoping that the publication of the present software package will promote the continuous researches in developing robust and reliable coastal and offshore renewable energy systems.

1. Introduction

Due to the explosion of energy consumption in household life, industrial production and public service in cities (as discussed in Ref. [1]), fossil resources are getting exhausted and there is a great need to establish sustainable energy systems for substitution. In recent years, coastal/ offshore renewable energies are becoming promising alternatives for the traditional fossil energies, attracting people's interest. Colmenar-Santos et al. [2] reviewed the state of the art of offshore wind technology and the most popular types of turbines, transmission systems and support structures in Europe. Lehmann et al. [3] reviewed the current state of ocean wave energy conversion technologies and industry status in the United States including research, development, commercial activities and governmental support. Khan et al. [4] reviewed the potentials of tidal current power as well as other ocean energy technologies and their environmental impacts. A great effort has been paid on the development of new methodologies, e.g., Vazquez and Iglesias [5] developed a new holistic method for selecting suitable tidal stream hotspots; Pavković et al. [6] presented a modeling, parameterization and control system design for the high-altitude wind energy system ground station power-plant. Efforts have also been made on finding new solutions from the existing theories, e.g., Bontempo and Manna [7] gave the exact solutions of the equations involved in the axial momentum theory for several kinds of radially variable load distributions; Liu and Yoshida [8] extended the Generalized Actuator Disc Theory to enable prediction of the axial velocity profile at the rotor plane of diffuser-augmented wind turbines. On the other hand, interests are focused on the laboratory development of a number of emerging offshore renewable energy devices, most of them being wave energy converters (WECs) because wave energy is a relatively nascent field,

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e.g., Elhanafi et al. [9] carried out a towing tank test on a floating–moored oscillating water column (OWC) wave energy converter and also conducted numerical investigations on the device performance and the effects from wave forces, wave height and power take-off damping, etc.; Wu et al. [10] studied the performance of a solo Duck wave energy converter in arrays under motion constraints; Ramos et al. [11] conducted a series of studies on assessing the feasibility of a CECO wave energy converter under the influences of water depth; Ning et al. [12] did extensive researches using both numerical tools and experimental facilities on the hydrodynamic performance of OWC devices. These case studies laid the foundations for the continuous future development of new efficient devices and technologies.

Hydrodynamic forces have a significant influence on the substructures of these offshore energy devices [13]. Liu et al. [14] reviewed the recent advancements of floating foundations for particularly the offshore wind turbines (OWTs) which have been turned into industrial applications. Oh et al. [15] further discussed their future trends and challenges. Note that in the design process of the coastal/ offshore renewable energy devices, one of the critical considerations is to evaluate the feasibility of these devices under some localized sea conditions (see e.g. [16]), i.e., to compute their wave loads and motion responses under various normal/extreme circumstances. In recent years, a variety of floating concepts have been proposed and developed for ocean energy converters (OECs), such as OWTs, WECs and tidal energy converters (TECs), for the industrial commercialization purpose. Several representatives of these newly developed floating OECs are shown in Table 1 and Fig. 1. These devices frequently employ floating foundations in the form of spar, tension-leg spar, semi-submersible, raft, and buoyancy-stabilized floater, etc., which are designed to be installed under the water depth going from approximately 20 m to around 200 m. Within such a range of moderate water depth, for the consideration of the offshore structure safety, it is more reasonable to use the finite-depth wave theory instead of assuming the installation water depth to be infinity.

So far, the boundary integral equation method (BIEM) (see e.g. [27]) has been widely applied in the assessment of offshore renewable energy systems. It is still one of the appropriate choices to solve efficiently their performance with wave-interactions (see e.g. [28]). That is because all its unknowns are restricted merely on the specified boundaries, which enables the computational burden to be greatly reduced. In BIEM, the boundary integral equations (BIEs) are derived via Green's theorem within a confined or unconfined space [29]. The BIEs can be numerically solved by discretizing the boundaries into a large number of mesh and physical elements. In the formulation of the influence matrices, Green's function and its derivatives must be evaluated successively for each pair of the source and the field points. The evaluation times of the 'core' function (Green's function) increase quadratically with the number of unknowns on boundary surfaces, especially for structures with complex geometries. In this context, accuracy and efficiency of computing the Green's function are crucial to a numerical solver for evaluating the performance of coastal/offshore renewable energy devices.

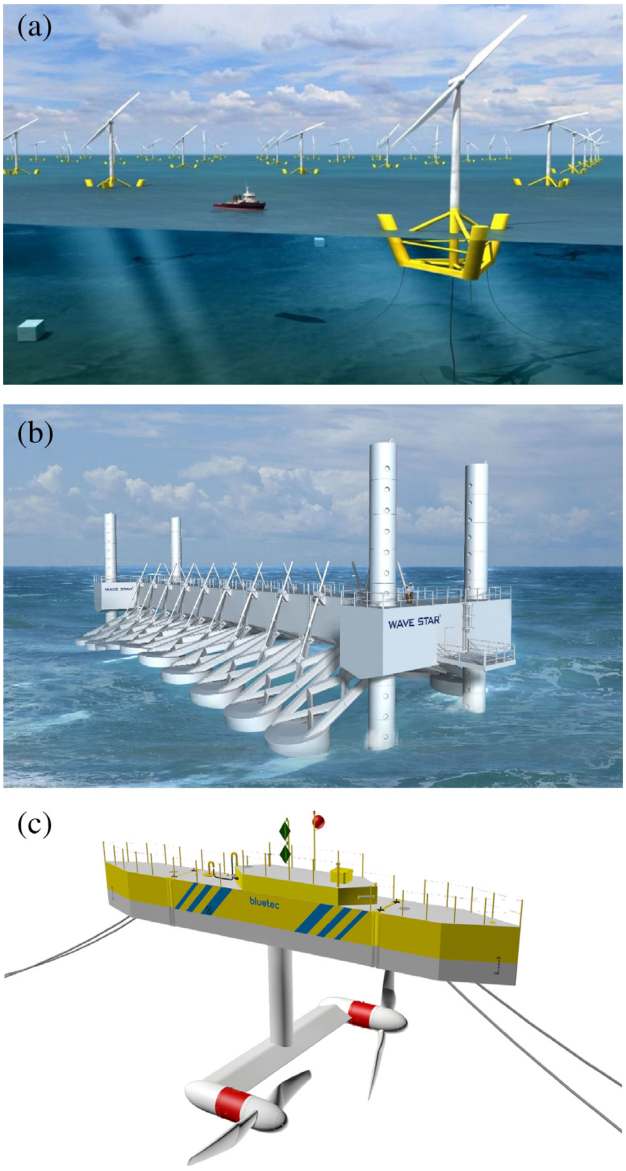

Fig. 1. Typical offshore renewable energy devices for the next generation applications: (a) WINFLO semi-submersible OWT [25], (b) WaveStar WEC [26], and (c) BlueTEC TEC [24]. Their designing installation water depth is intermediate rather than infinite.

Computational issues related with free-surface Green's function in hydrodynamics remain to be in the spotlight due to the popularity of the BIEM in the numerical analysis of ocean wind/wave/tidal energy

Table 1
Representative offshore renewable energy devices developed in recent years.

Device Name	Device Type	R&D Company	Offshore Site	Floater Type	Water Depth (m)	Rated Power	Current Status
Hywind® [17]	HAWT	Statoil	Norway	Spar	210	2.3 MW	Launched in 2009
WindFloat® [18]	HAWT	Principle Power	Portugal	Semi-submersible	50	2 MW	Launched in 2011
SWAY® [19]	HAWT	SWAY A/S	Norway	Tension leg spar	121	2.5–10 MW	Scaled Prototype in 2012
HiPR®-Wind [14]	HAWT	EU FP7 Team	Spain	Semi-submersible	50–90	1.5 MW	Designing stage in 2018
SCD®-nezzy [20]	HAWT	Aerodyn	Japan	Semi-submersible	52	6–8 MW	Under demonstration in 2018
SeaTwirl® [21]	VAWT	SeaTwirl	Sweden	Buoyancy stabilized	50	30 kW–1 MW	S1 released in 2015, S2 to be released in 2020
Pelamis® [22]	WEC	Pelamis Wave Power	Scotland	Raft	50	750 kW	Field test in 2010
SEAREV® [23]	WEC	CNRS	France	Semi-submersible	30–50	68–188 kW	G21 demonstrated in 2014
BlueTEC® [24]	TEC	Bluewater et al.	Netherland	Semi-submersible	20 ~	200 kW–2.5 MW	Launched in 2016