Ocean Engineering 159 (2018) 1–8

Contents lists available at ScienceDirect

Ocean Engineering

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

Experimental and numerical study of hydrodynamic responses of a new combined monopile wind turbine and a heave-type wave energy converter under typical operational conditions

Nianxin Ren[a,b,c], Zhe Ma[a,b], Tianhui Fan[d,*], Gangjun Zhai[a,b], Jinping Ou[a,b]

[a] Deepwater Engineering Research Center, Dalian University of Technology, Dalian, 116024, China
[b] State Key Laboratory of Coast and Offshore Engineering, Dalian University of Technology, Dalian, 116024, China
[c] Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, Beijing Jiaotong University, Beijing, 100044, China
[d] School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, 510641, China

ARTICLE INFO

Keywords:
Monopile
Wind turbine
Wave energy converter
Hydrodynamic response
Model tests

ABSTRACT

This paper deals with a new concept by combining a monopile type wind turbine and a heave-type wave energy converter, that is referred as the 'MWWC' (Monopile-WT-WEC- Combination) system herein. Hydrodynamic responses of the MWWC system under typical operational seas cases have been investigated by using both time-domain numerical simulations and scale model tests (1:50). For the numerical model, hydrodynamic loads of the monopile and the WEC are calculated by the AQWA code, which is available for modeling multi-body systems including both mechanical and hydrodynamic couplings between the TLP and the WEC. The scale model tests have been done in State Key Laboratory of Costal and Offshore Engineering (SLCOE). The power-take-off (PTO) system of the WEC device is simulated by two nonlinear air-dampers. Main hydrodynamic characteristics of the MWWC system under typical operational sea cases have been clarified. The obtained wave power characteristic and maximum PTO damping force of the WEC are very helpful for the optimal design of the operational performance of the PTO system. Numerical and experimental results are presented and compared, and good agreements are achieved.

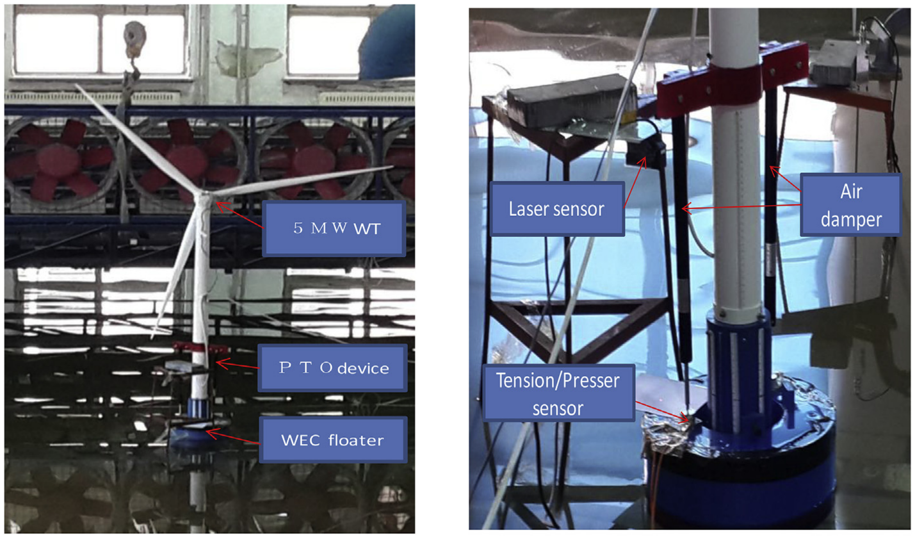
1. Introduction

Offshore wind energy has been the best commercialized and the most rapidly growing in the last decade among ocean renewable energy (ORE) resources, especially for the near-shore wind farm with monopile fixed-bottom foundation. Due to natural correlation, ocean wave energy may also be considerable where the offshore wind energy resource is rich. If offshore wind energy and wave energy are utilized simultaneously with possible combined wind turbine (WT) and wave energy converter (WEC) supporting structure system, the cost of the wave energy will be effectively reduced, as well as more ocean renewable energy will be utilized.

The EU project, MARINA Platform (MARINA PLATFORM), was dedicated to the investigation of a set of integrated platforms for the multi-purpose utilization of ORE resources, which mainly focus on the combined WT and WEC floating platform systems. Two combined WT and WEC systems have been proposed based on the same semi-submersible type floating wind turbine (FWT) 'WindFloat': one with an oscillating-water-column (OWC) type WEC, the other with a point-absorber type WEC. Main dynamic characteristics of the two combined systems have been investigated using both numerical and laboratory models (Aubault et al., 2011; Peiffer et al., 2011). Another semi-submersible combined ORE system was proposed, which consists of a 5 MW WT and three rotating-flap type WECs (denoted as the SFC). It was found that the additional rotating-flaps WEC could increase the power production without significantly affecting the behavior of the semi-submersible platform (Michailides et al., 2016). Based on a floating tension leg platform (TLP), a combined 5 MW WT and three point-absorber WECs system has been proposed, and the performance under both operational and extreme sea cases has been studied with coupled Simo-Riflex-Aerodyn code (Bachynski and Moan, 2013). Based on a floating spar type platform, a combined concept (denoted as the STC), consist of a 5 MW WT and a torus-shaped point-absorber type WEC has been proposed. It was found that the STC system could effectively increase total power production (Muliawan et al., 2012, 2013a, 2013b).

* Corresponding author.
E-mail address: fanth@scut.edu.cn (T. Fan).

https://doi.org/10.1016/j.oceaneng.2018.03.090
Received 2 December 2017; Received in revised form 24 January 2018; Accepted 31 March 2018



a) Overall view of the MWWC model b) Local monitoring sensors

Fig. 1. Scaled model test system.

Possible slamming and green water effects of the torus during extreme sea case have been investigated, and a nonlinear numerical solver was used to predict these strongly nonlinear phenomena with good agreements with corresponding model tests (Wan et al., 2015, 2016a, 2016b). In addition, the long-term performance in terms of annual power production, structural fatigue damage, and extreme responses of the STC system has been further investigated using coupled wind-wave analysis in the time domain, with the consideration of effect of different survival modes (Ren et al., 2014, 2015). So far, there is limited information about the conceptual design of the combined WT and WEC systems based on the fixed -bottom foundation for near shore shallow water.

The present work addressed a new concept by combing a mono-pile wind turbine with a heave-type wave energy converter, which is referred as the 'MWWC' (Monopile-WT-WEC Combination) system herein. Concept feasibility study has been carried out by doing both numerical simulations and scale model tests. The effect of different wave conditions on the performance of the WEC's wave energy production has been investigated. The hydrodynamic characteristic of the MWWC system has been mainly investigated under typical operational sea cases. Overall agreement between numerical results and test data is good, although slight differences attribute to viscous effects are observed.

2. Experimental model

The concept combining the monopile WT with heave-type WEC is mainly inspired by the STC system developed by NTNU (Muliawan et al., 2013a, 2013b). Considering the monopile type WT system is the most widely used in near shore zone, the spar FWT in the STC system is tentative to be replaced with the fixed-bottom monopile WT. The monopile type WT combines with the same heave-type wave energy converter, which is named as MWWC system.

The scale model tests of the MWWC system have been done in the State Key Laboratory of Costal and Offshore Engineering (SLCOE) at Dalian University of Technology, where there is a standard wave flume (with the size of 50 m*5.0 m*1 m). The range of the test wave height can be from 0.02 m to 0.5 m with the test wave period from 0.5s to 5.0s. Comprehensively considering conditions of the laboratory and the size of full-scale 5 MW monopile WT and heave-type WEC combination (MWWC) system, the scale ratio of the MWWC test model has been designed to be 1/50. The water depth for the full scale model test is 15 m. The overall view of the main combined structure system is shown in Fig. 1a, and locations of installed sensors for monitoring main dynamic responses of the MWWC system are shown in Fig. 1b. As it is known to us, it is very difficult to balance the similarity between Froude number and Reynolds number in such scale model tests. So the scale model was mainly based on the scaling law of the similarity of Froude number (Wan et al., 2016a, 2016b). The scale test model is mainly made of organic glass, and the main design parameters of which are list in Table 1.

Table 1
Main design parameters of the MWWC model.

Parameters	Full scale	Scaled ($\lambda = 1/50$)
NREL 5WM Wind turbine		
Blades and Nacelle mass (kg)	350,000;	2.80;
Tower mass (kg)	350,000	2.80
Tower Height(m)	90	1.80
Monopile diameter (m)	6.0	0.12
Water depth (m)	15	0.30
WEC device		
WEC floater(m)	$D_{out} = 16$; $D_{in} = 8$	$D_{out} = 0.32$; $D_{in} = 0.16$
Height & Draft (m)	$h = 8$; $h_d = 3.0$	$h = 0.16$; $h_d = 0.06$
Center of mass	(0, 0,-1 m)	(0, 0,-0.02 m)

Blades of the test wind turbine model can rotate with different angle velocities and different pitch angles, which can effectively comply with the similarity principle of mean wind thrust force according to the NREL 5 MW wind turbine (Jonkman et al., 2007). The monopile foundation of the scale model has been simplified as fixed bottom at the mud surface without soil-pile interaction effect. There is a high-frequency force balance (with a sensitivity of 0.01 N) at the bottom of the wind turbine tower, which is used for measuring six-DOFs' loads acting on the monopile.

The linear guide-roller system is set between the WEC floater and the monopile, which consists of four symmetrical guide-rollers. The vertical linear guides are set up on the monopile, and the rollers are set up on the WEC floater. The WEC floater can move vertically along the monopile though the linear guide-roller system, with very low friction effect.

The WEC's PTO system in the prototype (Wavebob, 2010) is simplified as two air-dampers (Wan et al., 2016a) in the test model. The air-damper can pump air in and out to simulate the absorption effect of the wave energy. Different damping levels can be obtained by tuning a nozzle on one end of the damper. On the other end of the damper, there is a piston rod that is connected to the top plate of the WEC floater through a tension/presser sensor (with a sensitivity of 0.01 N), which is used to measure the PTO damping force. The working principle of the air damper