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W2P: A high-power integrated generation unit for offshore wind power and ocean wave energy

Weixing Chen[a,*], Feng Gao[a], Xiangdun Meng[a], Bin Chen[a], Anye Ren[b]

[a] State Key Laboratory of Mechanical System and Vibration, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China
[b] Institute of Aerospace System Engineering Shanghai, Shanghai, China

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ABSTRACT

Energy resources of offshore wind and ocean wave are abundant, clean and renewable. Various technologies have been developed to utilize the two kinds of energy separately. We present a high-power integrated generation unit for offshore wind power and ocean wave energy (W2P). The unit includes that: (1) The wind wheel with retractable blades and the 3-DOF (degrees of freedom) mechanism with the hemispherical oscillating body are used to collect the irregular wind and wave power, respectively; (2) The energy conversion devices (ECDs) are utilized to convert mechanical energy from both the wind wheel and the 3-DOF mechanism into hydraulic energy; (3) The hydraulic energy is used to drive the hydraulic motors and electrical generators to produce electricity. Some analyses and experiments have been conducted to obtain the performance of the key components of the unit. Based on the layout method, the single row wind-wave power plant is established.

1. Introduction

Offshore wind power and ocean wave energy originate from the solar energy. Both of the two kinds of energy are abundant, widely distributed and renewable energy resources awaiting exploration (Zheng et al., 2012, 2014; Cornett, 2008; Wu et al., 2015).

There are mainly three types of offshore floating wind turbine generator (WTG) classified by the floating platform including Spar floater (Skaare et al., 2007; Karimirad et al., 2009), Tension leg platform (Bir and Jonkman, 2007; Sclavounos et al., 2010) and Semi-submersible platform (Henderson et al., 2003; Carballo and Iglesias, 2013; Abanades et al., 2014). The conventional WTGs (the gear-driven train and the direct drive train) are used for offshore wind power utilization (Bilgili et al., 2011; Sun et al., 2012). However, the gear-driven train has the disadvantages of the failure of the gearbox and the high maintenance cost of the generator and the gearbox in the nacelle. The direct drive train has the expensive, high-torque and precisely controlled generators which are larger than ordinary ones, increasing the cost. So far, there have emerged some design concept of offshore WTG (Jones et al., 2012; Jones and Chao, 2011). The hydraulic WTG can remove the gearbox and install the generator on the ground, which can reduce the mass on the top of the tower and the cost of installations and maintenance.

The ocean wave energy converters (WECs) are still in the research stage (Falnes, 2002; Scruggs and Jacob, 2009; Cruz, 2007). There are three principles of WECs (Falcão, 2010), including the oscillating water column (Masuda, 1986; Brito-Melo et al., 2008; Setoguchi and Takao, 2006), the oscillating body system (Salter, 1974; Budar and Falnes, 1975; Weinstein et al., 2004; Ruellan et al., 2010; Henderson, 2006; Al-Habaibeh et al., 2010) and the overtopping converter (Kofoed et al., 2006; Vicinanza and Frigaard, 2008). Among various technologies, the oscillating body systems have been investigated widely in the recent years, which almost have one DOF. The performance of various WECs have been numerically studied (Babarit et al., 2012), and the results indicate that the efficiency of numerous oscillating systems are not very high.

The combined exploitation of offshore wind power and ocean wave energy is a very recent research topic (Pérez-Collazo et al., 2015). Currently, there are two types of combined wind-wave systems: co-located and hybrid, some of which emerge on the website. Co-located systems combine the wind farm and the wave array with independent foundation, such as Wave Star (2012), Wave Treader (Power-technology.com, 2010) and WEGA (Renewable Energy Focus, 2010). Hybrid systems are that offshore WTGs and WECs are installed on the same platform working as an unit, such as W2Power (Pelagic PowerAS, 2010) and Poseidon (Floating Power Plant AS, 2013). The modeling and testing of some combined systems are also performed (Peiffer et al., 2011; Peiffer and Roddier 2012; Muliawan et al., 2013). Besides these designs, some experts believe that the combined systems have great perspectives (Astariz et al., 2015a, 2015b; Astariz and Iglesias,

* Corresponding author.
E-mail address: cwxsjtu@163.com (W. Chen).

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Nomenclature

H_s	significant wave height	$S(\omega)$	irregular incident wave spectrum
T_e	wave energy period	q	factor of WEC array
v	wind speed	N	number of WECs
D_1	diameter of the wind wheel	P_{wind}	power absorbed by the wind wheel
D_2	diameter of the hemisphere	P_0	power output of one unit
θ	output angle of the heave motion of WEC	η_t	hydraulic transmission efficiency
ψ	output angle of the pitch motion of WEC	η_g	the efficiency of the hydraulic motor and the electrical generator
Φ	output angle of the roll motion of WEC	$\bar{q}$	average of q factors
β	wave direction	M	number of the units
P_{wave}	mechanical power absorbed of the WEC from waves	T	horizontal distance among units
η	efficiency of the ECD	S	vertical distance among units
		P	power output of the plant

2016).

In this paper, the concrete design of a hybrid system W2P is presented, which is able to convert the two kinds of energy into electricity through the hydraulic energy transmission and the same ECDs. When the significant wave height H_s, the wave energy period T_e and the wind speed v are equal to 4 m, 10 s and 13.5 m/s respectively, the unit and wind-wave power plant are presented. Based on the numerical model and experiment, the power output of the unit and wind-wave power plant is calculated to be 16.7 MW and 100 MW, respectively.

2. Principle and performance of the W2P

The principle of the integrated generation is shown in Fig. 1. The wind wheels, the oscillating bodies and the absorption mechanisms collect and deliver wind power and wave energy, and convert them into mechanical energy. The energy converters transform mechanical energy into hydraulic energy which is stored in accumulators. The hydraulic energy is transformed into electrical energy through the hydraulic motors and electrical generators. Then the wind-wave power plant established by the principle can provide power for the residential electricity, the mining equipment, the hydrogen production, the sea water desalinization and so on.

Based on the principle of the integrated generation, the high-power W2P is proposed (Fig. 2a). The W2P consists of one large floating platform, one WTG, three WECs and a set of generating equipment including several groups of accumulators, hydraulic motors and electrical generators.

The wind wheel with retractable blades (Fig. 2b) collect the irregular wind power, which can adapt to a wide range of wind speeds and withstand extreme wind conditions because of using the retractable blades. The 3-DOF mechanism with the hemispherical oscillating body (Fig. 2d) is used to collect the irregular wave power efficiently, which can decouple the three motions (heave, roll and pitch) of the oscillating body. The ECDs (Fig. 2c and e) are utilized to convert mechanical energy from both the wind wheel and the mechanisms into the same hydraulic energy. Finally, the stable hydraulic energy stored in accumulators is used to drive the hydraulic motors and electrical generators to produce electricity (Fig. 2f). The W2P has some characteristics (2E3S):

(1) Enhanced power export. The unit can increase the energy yield per unit area of seas. The W2P can be grouped to realize great power output.
(2) Efficient power yield. The wind wheel can adjust the diameter and the velocity according to the wind speeds to achieve the maximum power coefficient. The 3-DOF mechanism can extract mechanical energy from three motions of oscillating bodies.
(3) Smoothed power output. The wave resource is more predictable and less variable than the wind resource. Some generators can be shut off to achieve the optimal rotational speed when the incoming wind power and wave energy decrease. The accumulators are used

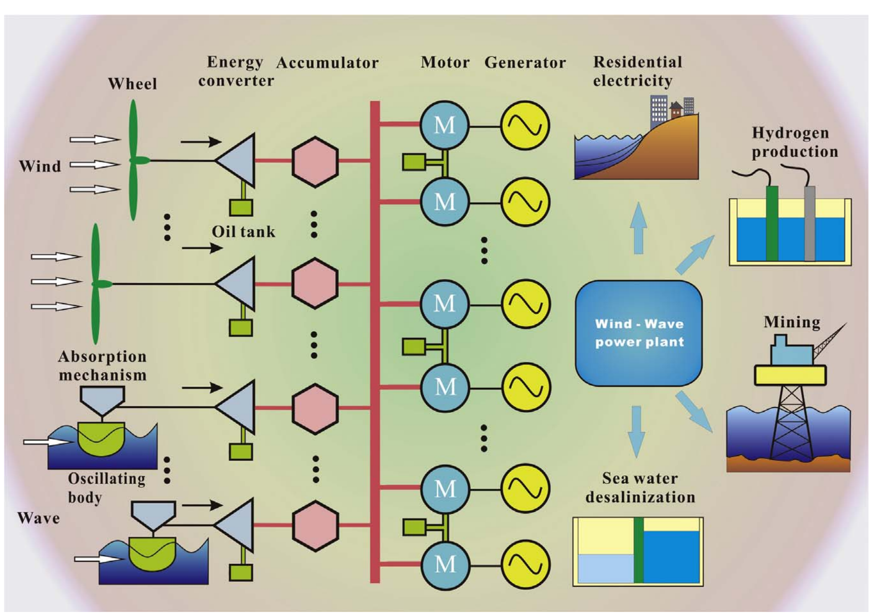

Fig. 1. Schematic of the integrated generation.