Overview on Hybrid Wind-Wave Energy Systems

Song Ding[1, a], Shiqiang Yan[2, b], Duanfeng Han[1, c], Qingwei Ma[2, d]

[1]College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China

[2]School of Mathematics, Computer Science and Engineering, City University London, London EC1V 0HB, UK

[a]dingsong2014@hotmail.com, [b]shiqiang.yan.1@city.ac.uk, [c]handuanfeng@hrbeu.edu.cn, [d]q.ma@city.ac.uk

Keywords: Renewable energy; Hybrid system; Floating wind turbine; Wave energy converter; Power performance

Abstract. As a relatively new concept combining floating wind turbine (FWT) and wave energy converter (WEC), Hybrid wind-wave energy system (HWWES) is still on its initial stage. The reason for this is that both WEC and FWT platforms have many subcategories but there is no common agreement about how to combine them together. Furthermore, as offshore device system, HWWES has special design requirement. A good HWWES should properly integrate selected WEC and FWT platform, improve overall performance and be cost effective. Not all kinds of FWT platforms and WECs are suitable to be applied for HWWES design. However, there is still no answer to question 'which type of WEC or FWT is more suitable for HWWES'. This paper overviews several existing HWWESs.

Introduction

To achieve a great power production and cost-benefit, there is a relatively new hybrid concept which combines the floating wind turbine with wave energy converter. By doing this, mooring system, electrical infrastructure, and other components are being shared with the existing floating wind turbine structure. The overall cost of installation, operation and maintenance can be decreased. Ideally, the wave energy converter (WEC) should be integrated so as to reduce the overall motion response of the platform, and could thus have a stabilizing effect on the whole system. The wind energy generation component of the system could come out enhanced. Some concepts of hybrid wind-wave energy system (HWWES) have been explored and the related numerical and experimental analyses are also carried out by previous researchers. According to Peiffer [1], an oscillating water column type WEC, a point absorber type WEC and an oscillating wave surge converter are respectively integrated into the semi-submersible type floating wind turbine (FWT) 'WindFloat'. According to Muliawan [2], an axis-symmetric two-body WEC such as 'Wavebob' is considered to be combined with the spar type FWT such as 'Hywind'. The Danish company Floating Power Plant installed a demonstrator of their Poseidon device in which a set of pitching type WECs are integrated on a stable cross-type platform [3]. A Norwegian company is developing a concept called W2Power, combining heaving point-absorbers and two wind turbines [4].

For the hybrid concept mentioned above, due to mechanical and hydrodynamic couplings between the floating bodies, the behavior of FWT would be changed by adding WEC [2]. A decrease in the power produced by FWT is not desirable but could also occur as the result of adding WEC. Hybrid wind-wave energy technologies are still in the initial stage. Although the addition of WEC seems decrease the overall cost and may improve the motion performance and power performance, meanwhile it also emerges many challenges and uncertainty that need to be figured out. In this paper, all categories of WECs and FWT support structures are overviewed and discussed. Some typical HWWESs are presented.

Wave energy converters

As one of the two main parts of HWWES, it is more difficult to select an ideal wave energy converter than the wind turbine since more than one thousand prototypes of WECs have been developed over the years. Several literature reviews of WEC devices have been published providing information about various aspects of the technology [5,6,7]. According to López [8], these devices, in general terms, can be classified according to three characteristics: working principle, location and size. Therefore, each WEC can be classified into several groups depending on its features.

Working Principle. As shown in A1, A2 and A3 of Fig. 1, there are three subcategories when WEC is classified by working principle [6]. A1 is oscillating water column (OWC), these converters comprise a partly submerged concrete or steel structure, open below the water surface, inside which air is trapped above the water free surface. A2 is oscillating body system, these converters are basically offshore devices, either floating or (more rarely) fully submerged. This type of devices is based on a floating body which is moved by the waves. A3 is overtopping converter, these converters capture the water that is close to the wave crest and introduce it, by over spilling, into a reservoir where it is stored at a level higher than the average free-surface level of the surrounding sea.

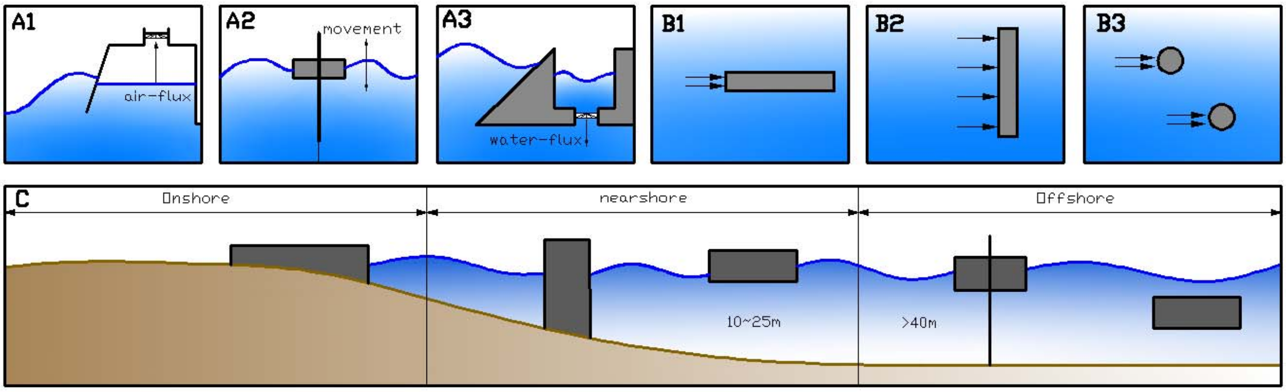

Fig. 1. Subcategories of WEC (A1-OWC; A2-Oscillating Body System; A3-Overtopping Converter; B1-Attenuator; B2-Terminator; B3-Point Absorber; C-Onshore, Nearshore and Offshore devices:)

Size and Direction. As shown in B1, B2 and B3 of Fig. 1, there are also three subcategories when WEC is classified by size and direction [8]. B1 is attenuator, which is long structure when compared with wave length. Placed in parallel with respect to the wave direction, attenuator attenuates the wave. B2 is terminator, which is similar to Attenuators, as they are also long structures. However, these ones are placed vertical to the direction of wave propagation. B3 is point absorber, these converters' size is smaller than the wave length. Wave energy can be absorbed in all directions through its movements. These devices convert the up-and-down pitching motion of the waves into their own movements (rotary or oscillatory) and then transfer the kinetic energy into electricity power.

Location. As shown in C of Fig. 1, obviously there are three subcategories when WEC is classified by location [8]. They are respectively onshore, nearshore and offshore devices.

When considering WEC for HWWES design, its location is firstly decided as offshore among the three features since the main working site for HWWES should be offshore. As for working principle, the oscillating body system shows advantages than the other two types of WECs (OWC and overtopping converter). Since the oscillating body system has many subcategories with different motion performances and combining forms (floating or submerged; one body, two bodies or even many bodies; heave, pitch or surge). This diversity makes oscillating body system more flexible when integrated with FWT platform than OWC and overtopping converter. As for size and direction, the advantages of point absorber make it a relatively reasonable choice for HWWES. For offshore wind turbines in a farm, each device should be spaced at a certain distance to account aerodynamic wake effect. In this term, placing point absorbers in the spaces of a wind farm seems like a more proper option.

Until now, each category of WEC has quite different feature and there is still no common sense about which kind of WEC should be the best choice or has obvious advantage over others [7]. In addition, WEC's performance also varies when coupled with different floating platforms. However, based on above comment, the three subcategories among the three different classifications (working principle, size and location) are respectively oscillating body system, point absorber and offshore device. These are just three features of WEC, not definitely three separate devices. It still depends on different specific situations and considerations.

Floating Wind Turbine Platform

When considering a new HWWES concept, the first step seems to choose a proper floating support structure to carry WEC and other parts of system before WEC selection. Only through a specific type of floating support structure as a basement can other following works be done (design proper WEC and mooring system, stability and hydrodynamic performance analysis and so on). In the offshore oil and gas industry, floating support structures have been used for many years. There are mainly three basic concepts: the spar, the barge and the tension leg platform (TLP), as simply sketched respectively in A, B and C of Fig.2.

The spar is a floating platform that mainly achieves static stability by the relative position of CG (centre of gravity) and CB (centre of buoyancy). It usually has a small radius cylinder, a deep draught and the ballast to lower the position of CG. The barge is a floating platform that mainly uses the waterplane area to achieve static stability. Its simplicity leads to a low cost. The tension leg platform (TLP) is a floating platform that achieves stability by exploiting a tensioned mooring system, based on several high tensioned lines anchored to the sea bed.

When considering floating structures for HWWES, another support structure, exploiting one or more of the above three principles illustrated, are usually mentioned: the tri-floater, as shown in D of Fig. 2. The tri-floater platform is based on three cylindrical columns linked by truss structure or pipe beams [9]. Usually the wind turbine tower is fitted at the geometrical centre of the structure, but in some situations it can also be fitted on top of the columns and therefore it is more challenge to obtain a good hydrodynamic response.

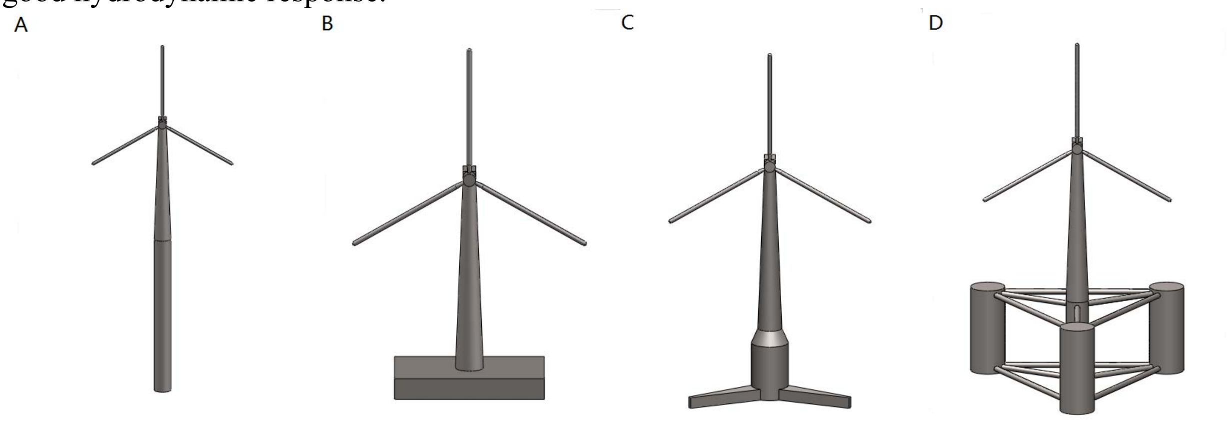

Fig. 2 Sketch of four different platforms based FWT (A-Spar Type; B-TLP Type; C-Barge Type Turbine; D-Tri-floater Type)

Existing Hybrid Wind-Wave Energy Systems

For existing HWWESs, most of the power production comes from wind turbine, WEC is still auxiliary [2]. Most hybrid systems are based on a fully developed floating wind turbine which is relatively easily for WEC to combine, like the Spar and the tri-floater. Both these two floating support structures have been well thought and considered to be more suitable to be integrated with auxiliary equipment (like WEC) than the barge and the TLP type platform. However, until now, for the specific HWWES design, there is no guideline for selecting floating support structures and WECs. Even for the existing hybrid systems, there is still no one which shows absolutely superior performance than others. Some concepts for combining wind and wave are summarized below.

Spar-Torus Combination (STC). This HWWES combines the spar type floating wind turbine (Hywind) with a point absorber type WEC (Wavebob), as sketched in Fig. 3, A1 is the spar type floating wind turbine, A2 is the hybrid system Spar-Torus Combination (STC). In this concept, the point absorber will slide along the Spar to extract energy from waves while the wind turbine generates power from the wind. In this way, the point absorber will benefit from using the FWT's mooring system as well as power cable. Their recent results show that STC has more stable motion performance and greater power output than Spar only situation [2].

In this combination, the point absorber and spar type floating platform are both simple and fully developed concepts. However, many challenges still remain related to the feasibility of the STC. For example, more study is required on how the system should be designed to maximize the performance of both the WEC and the wind turbine. The whole system should also be designed to meet the requirement of the ultimate limit state (ULS) and the fatigue limit state (FLS) in operational mode. Proper methods need to be studied to quantify the interaction between the WEC and the wind turbine. Furthermore, as offshore devices, the survival of the system during extreme condition is very important. Therefore, feasibility in survival mode and appropriate survival strategies of the hybrid system under extreme condition also need to be investigated [10].

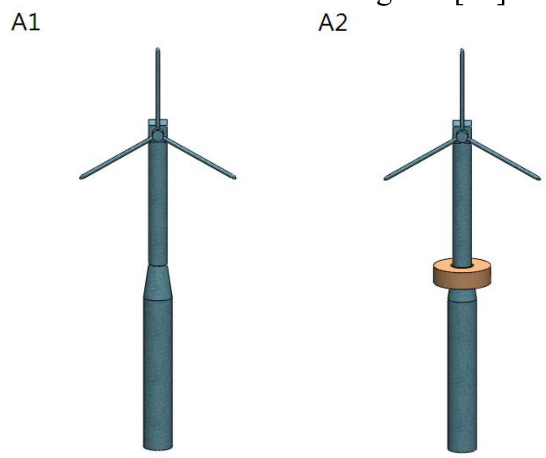

Fig. 3 Simplified Sketch for STC (A1-Spar Type FWT; A2-STC)

WindWaveFloat. This HWWES combines the tri-floater floating wind turbine with several kinds of WEC (point absorber, OWC and oscillating wave surge converter respectively) as sketched in Fig.4. In the first case, a point absorber is placed within the WindFloat platform as shown in B2 of Fig.4. The point absorber is attached to the WindFloat by three lines. In the second case, two oscillating wave column (OWC) is installed on some columns of WindFloat as shown in B3 of Fig.4. In the third case, three hinged rectangular flaps (flat stiffened vertical plates, oscillating surge converter) are installed on the top main beams of the WindFloat platform, as shown in B4 of Fig.4. The flaps oscillate back and forth as they are motivated by incoming waves. More details of the three different combinations of WindWaveFloat concepts can be found in [1,11,12]. In that paper, both numerical calculation and experimental analysis are carried out and some typical differences have been highlighted among the results. For example, with effects of adding the WEC, the motion of whole system is reduced compared without the WEC. In addition, as the auxiliary in the hybrid system, the normalized power capture width of WEC can also reach up to 47%. The comparison results show the feasibility of WindWaveFloat and its value for further optimization.

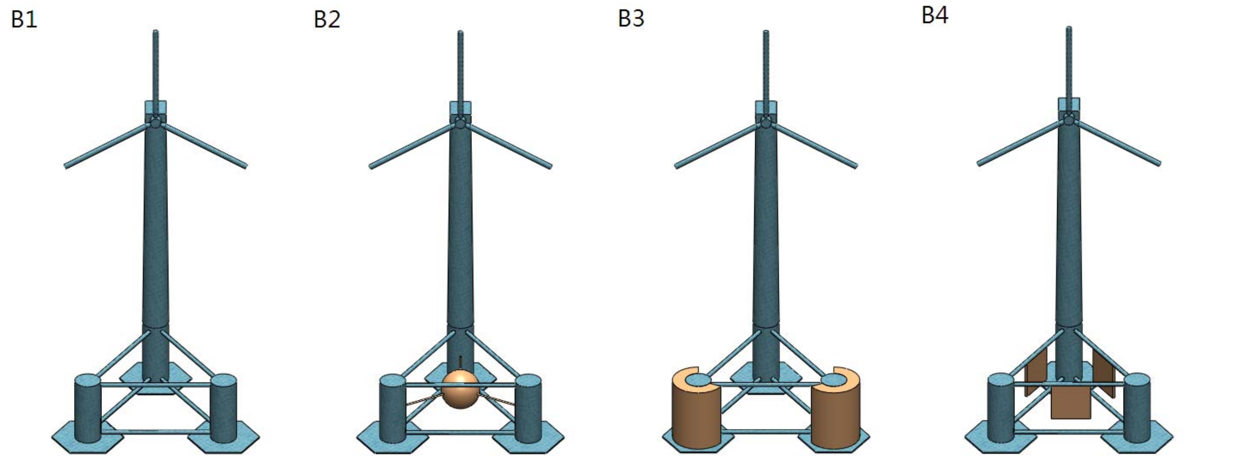

Fig. 4 Simplified Sketch for WindWaveFloat (B1-Tri-floater Type FWT; B2-Tri-floater and a point absorber; B3-Tri-floater and two OWC; B4-Tri-floater and three oscillating surge converter)

Conclusions

In this paper, a hybrid wind-wave energy system is overviewed and discussed. The two main parts of this hybrid system, floating wind turbine system and WEC, with all their subcategories are described when selected for hybrid systems. The literature seems to suggest that the point absorbers are suitable for WEC to be used in HWWES and SPAR type FWT and tri-floater type FWT are considered as proper choices as the support structure in HWWES. As examples, two typical existing hybrid wind-wave energy systems, STC and WindWaveFloat, are discussed to give some insight into the flexibility of combining FWT with WEC.

References

[1] Peiffer, Antoine, and Dominique Roddier. "Design of an oscillating wave surge converter on the windfloat structure." *Proc*. 2012.

[2] Muliawan, Made Jaya, Madjid Karimirad, and Torgeir Moan. "Dynamic response and power performance of a combined spar-type floating wind turbine and coaxial floating wave energy converter." *Renewable Energy* 50 (2013): 47-57.

[3] Information on http:// www.floatingpowerplant.com/

[4] Information on http:// www.pelagicpower.no/

[5] Li, Ye, and Yi-Hsiang Yu. "A synthesis of numerical methods for modeling wave energy converter-point absorbers." *Renewable and Sustainable Energy Reviews* 16.6 (2012): 4352-4364.

[6] Antonio, F. de O. "Wave energy utilization: A review of the technologies."*Renewable and sustainable energy reviews* 14.3 (2010): 899-918.

[7] Falnes, Johannes. "A review of wave-energy extraction." *Marine Structures*20.4 (2007): 185-201.

[8] López, Iraide, et al. "Review of wave energy technologies and the necessary power-equipment." *Renewable and Sustainable Energy Reviews* 27 (2013): 413-434.

[9] Roddier, Dominique, et al. "A generic 5 MW WINDFLOAT for numerical tool validation & comparison against a generic spar." (2011).

[10] Muliawan, Made Jaya, et al. "Extreme responses of a combined spar-type floating wind turbine and floating wave energy converter (STC) system with survival modes." *Ocean Engineering* 65 (2013): 71-82.

[11] Peiffer, Antoine, Dominique Roddier, and Alexia Aubault. "Design of a point absorber inside the WindFloat structure." *ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering.* American Society of Mechanical Engineers, 2011.

[12] Aubault, Alexia, et al. "Modeling of an oscillating water column on the floating foundation WindFloat." *ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering*. American Society of Mechanical Engineers, 2011.