Review of Hybrid Offshore Wind and Wave Energy Systems

To cite this article: Kaylie L. McTiernan and Krish Thiagarajan Sharman 2020 *J. Phys.: Conf. Ser.* **1452** 012016

Review of Hybrid Offshore Wind and Wave Energy Systems

Kaylie L. McTiernan[1,*], Krish Thiagarajan Sharman[1,]**

[1]Mechanical Engineering, Gunness 9C-D, University of Massachusetts Amherst, 160 Governors Drive, Amherst, MA 01003

[*]kmctiernan@umass.edu, [**]kthiagarajan@umass.edu

Abstract. Hybrid wind wave systems combine offshore wind turbines with wave energy on a shared platform. These systems optimize power production at a single location by harnessing both the wind and the waves. Wave energy is currently at an earlier development stage than offshore wind. Research in this area is focused in wave energy converters being used for platform motion suppression of floating offshore wind turbines. Wave energy converters can passively shelter offshore wind turbines from waves and can also be actively controlled to reduce the system loads. Additionally, a small amount of supplemental power may be generated, which can be used for offshore wind turbine local power needs. There may be future benefits to these hybrid systems, but at this stage wave energy may increase the project cost and risk of offshore wind turbines. Hybrid wind wave system research and development is discussed, with a focus on floating offshore wind turbines. Additionally, two ocean demonstration scale hybrid wind and wave systems are discussed as case studies: the Poseidon Wave and Wind system and the W2Power system. Hybrid wind wave systems show potential to be part of the future of offshore wind energy.

1. Introduction

Wind energy production has been moving offshore due to the strong wind resource and open space at sea. There are many people living near coastlines globally who can benefit from offshore power. While harnessing power from the wind at sea, there is also an opportunity to harness the power of waves. Wind waves are generated by the wind blowing over the surface of the ocean over a large area and these waves travel over long distances. Waves can build up to average energy densities of 100 kW/m over a 1 m wave front [1], which is significantly more energy dense than solar and wind resources [2]. Figure 1 by Gunn et al. [3] shows the global annual mean wave power density.

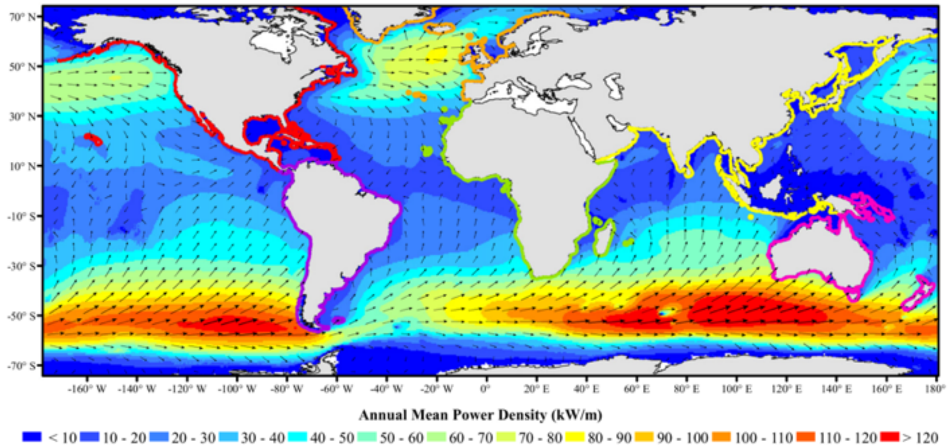

Figure 1 - Annual Mean Wave Power Density (kW/m). Large Wave Power Density regions exist around 50°N and 50°S (red represents highest wave power density and arrows represent predominant direction). From Gunn et al. [3]

This paper will review hybrid offshore wind and wave energy systems (hybrid wind wave systems). Hybrid wind wave systems are defined by Pérez-Collazo [4] as an offshore wind turbine combined with a wave energy converter (WEC) on a shared platform. Hybrid wind wave systems are distinct from collocating wind energy and wave energy in the marine space on separate platforms. Wave energy has been an ongoing research area, but is still in a much earlier development stage than wind energy. Hybrid wind wave systems are a relatively new research area, which has been receiving specific funding pathways in Europe to encourage optimizing energy extraction in the marine space [4]. This paper will review the types of hybrid wind wave systems, the advantages and challenges of these systems, the details of two case study systems, and conclude with a future vision of hybrid wind wave systems.

2. Background: Types of Hybrid Wind Wave Systems

This review focuses on hybrid floating offshore wind turbine platforms, although hybrid fixed offshore wind turbines with WECs are another research area [5]. There are three primary types of floating offshore wind platforms including spars (ballast stabilized), semisubmersible (buoyancy stabilized), and tension leg platforms (mooring stabilized) [6]. Thus far, most hybrid wind and wave system research and development has included both ballast stabilized and buoyancy stabilized platforms [4]. One notable hybrid wind wave system was developed by Principle Power of the USA, the WindWaveFloat [2,7]. The WindWaveFloat is similar to Principle Power's offshore wind turbine, the WindFloat, which includes one wind turbine on a semisubmersible platform (Figure 2). Principle Power has researched many types of wave energy converters on their hybrid system, both numerically and experimentally [7]. Wave energy converters span a large design space as they have not yet reached technology convergence.

 1452 (2020) 012016 doi:10.1088/1742-6596/1452/1/012016

Figure 2 - WindFloat Offshore Wind Turbine by Principle Power [2]

2.1. Types of Wave Energy Converters

There are many types of wave energy converters under development which span nearshore and offshore locations as well as shallow, intermediate, and deep water depths. WECs can be primarily classified as oscillating water columns, oscillating bodies, and overtopping devices as shown in Figure 3 [4,8]. An oscillating water column has a chamber with entrapped air which is compressed by the changing wave pressure. Oscillating bodies generate energy by their motion relative to a stationary body. The overtopping devices use the potential energy of water to power a low head turbine. Full scale WECs are designed to produce power on the order of 1 MW, but most scaled demonstration projects are on the order of 500 kW and span 10 - 150 m in length [1]. Hybrid wind wave systems include a wide variety of WEC device types, but most commonly include an oscillating water column or oscillating body [2,7]. There are many research studies on hybrid wind wave systems and some ocean scale demonstration projects.

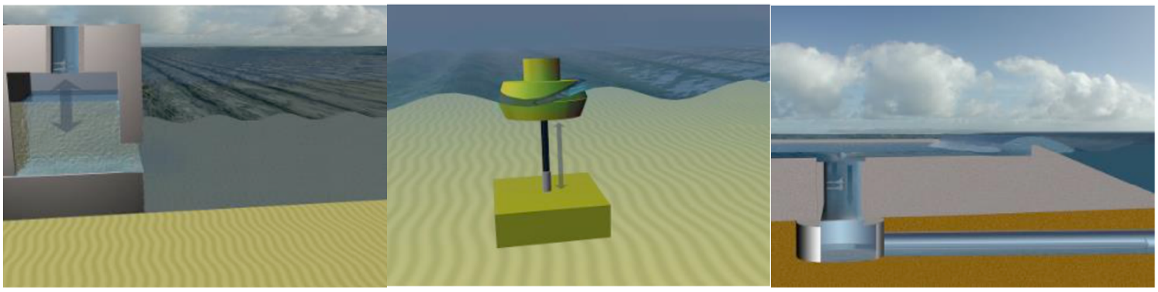

Figure 3 - Types of Wave Energy Converters: Oscillating Water Column (left), Oscillating Bodies (center), Overtopping Devices (right) [8]

3. Hybrid Wind Wave Case Studies

The two most notable hybrid wind wave systems are the W2Power by Pelagic Power and the Poseidon Wave and Wind by Floating Power Plant [2,7,9,10]. Both of these systems have reached demonstration scale ocean deployments. A summary of the ocean test scale and full scale hybrid systems are shown in Table 1 and Table 2 respectively [2,7].

Table 1. Case Study Scaled Ocean Demonstration

	W2Power	Poseidon37
Scale	1:6	1:4
Ocean tests incl. WECs	no	yes
Scaled wind power (kW)	Unknown	33
Scaled WEC power (kW)	-	30
Wind turbine type	Unknown	Gaia 3x11 kW
WEC type	Oscillating body	Oscillating body or oscillating water column

Table 2. Case Study Full Scale Systems

	W2Power	Poseidon80
Full scale power (MW)	9.2-10.2	4.9-7.6
Wind power (MW)	7.2	2.3-5
WEC power (MW)	2-3	2.6
Wind turbine type	Siemens 2x3.6 MW	Unknown

3.1. Case Study 1: W2Power

The W2Power Wind and Wave system by Pelagic Power includes a semisubmersible offshore wind turbine platform with two wind turbines and multiple oscillating body WECs [9,10]. W2Power was developed by Pelagic Power of Norway and has included numerical modeling, tank testing, controls development, and ocean demonstration projects. The full scale W2Power is designed to produce 10 MW of power, including 2 x 3.6 MW wind turbines and 2-3 MW from wave energy. A 1:6 scale device has been tested near the Canary Islands with the wind turbines but no WECs. An artistic depiction of the W2Power is shown in Figure 4.

Figure 4 - W2Power Hybrid Wind Wave System by Pelagic Power [4]

3.2. Case Study 2: Poseidon

The Poseidon Wave and Wind system by Floating Power Plant has a buoyancy stabilized platform with three wind turbines and multiple WECs [2]. The Poseidon was developed by Floating Power Plant of Denmark. The full scale Poseidon system can be 80 - 150 m depending on the site and a 37 m scale model has been tested at sea offshore of Denmark, shown in Figure 5. The 37 m scale model includes 10 x 3 kW WECs and 3 x 11 kW wind turbines [7]. The Poseidon includes both oscillating body and oscillating water column WECs. The full-scale Poseidon system will include 2.6 MW from oscillating water columns and 2.3-5 MW from wind turbines. The development of hybrid wind wave systems demonstrates future potential, and has emphasized both the advantages and the challenges of combining wind and wave power generation on a common platform.

Figure 5 - Poseidon Hybrid Wind Wave System by Floating Power Plant [2]

4. Advantages

Hybrid wind wave systems produce energy from wind and waves in the same marine space, which may be an ideal renewable energy system of the future. Generating wind and wave energy on a common platform would ideally improve the levelized cost of energy, increase the amount of power generated, and reduce the structural loading on the offshore platform. Future visions of hybrid wind wave systems include an offshore platform that optimizes use of the marine space as it generates significant power at a reasonable cost. The common platform enables maintenance and grid connections to be streamlined as compared with two separate systems, and may provide improvements for both CAPEX and OPEX [2]. In addition to technical and economic advantages, other marine users may appreciate the optimal use of space and less exclusionary zones of hybrid wind wave systems from social and environmental perspectives. WECs also provide less viewshed impacts than wind turbines. Further, WECs can be more densely spaced together, while wind turbines need greater spacing for wind wakes. Once WEC technology has been advanced, multiple WECs producing 1 MW each would be a significant contribution to a 5-10 MW offshore wind turbine. Power from the wind and waves can balance one another, and wave energy can help smooth power fluctuations during periods of less wind. The greatest advantage of hybrid wind wave systems at this stage of development is using WECs to suppress platform motion and to provide local power needs.

4.1. Floating Offshore Wind Platform Motion Suppression

Wave energy can be used to reduce the motion of offshore wind turbine platforms both actively and passively. Wave energy converters absorb energy from the waves and thus dampen the wave field. This creates a shadow effect which naturally suppresses platform motion due to waves [2]. Additionally, WECs can be actively controlled to suppress the motion of offshore wind platforms. The reduced platform motion is important for system fatigue and for helping the wind turbine operative most efficiently, with minimum motions at the hub. Actively suppressing offshore platforms with WECs is still in early research stages, but numerical and test tank results are promising.

Several research studies have found that offshore wind turbine platform motion has been reduced by using WECs. Haji et al. [11] studied a hybrid system consisting of a spar offshore wind turbine with three wave energy converters and found a 23% reduction in fatigue loads on the floating offshore wind turbine platform. Kluger [12] studied a hybrid spar with WECs numerically and experimentally and found a reduction of surge motion of 16%, a reduction of pitch motion by 21%, and a reduction in fatigue stress of 6% with a single WEC. Zhu et al. [13] implemented WEC control to reduce the pitch motion of a semisubmersible offshore wind turbine up to 50%. Borg et al. [14] studied a hybrid semisubmersible with a WEC and found the optimal WEC natural frequency, damping, and stiffness values needed to minimize platform motion and maximize power output. These research studies found that WECs can be used to suppress the platform motion of offshore wind turbines, but results are specific to the offshore platform, WEC, and control system.

Hybrid wind wave systems are advantageous when the WECs suppress platform motion, but more research is needed in this area. Some studies have found an increase in platform motion resulting from WECs. Muliwan et al. [15] found that the hybrid spar platform with WECs that was analyzed had greater mooring and tower loading in survival conditions resulting from WEC loading in rough seas. Kelly et al. [16] studied a hybrid spar platform with WECs and found large pitching motion because the system was often operating in the resonant pitch period of the structure. These results indicate that more research on the controls of hybrid wind wave systems are needed to ensure that platform motion is reduced by WECs rather than increased in some cases.

4.2. Local Offshore Wind Power Needs

In addition to reducing structural loading, WECs can be used to provide local power for floating offshore wind turbine systems. A main advantage of hybrid wind wave systems is that the power from WECs may be advantageous as a local power source. Offshore wind turbines may need local power for operating a ballast system or controls system. Diesel power is sometimes used in these circumstances, and wave energy would be a renewable energy alternative. Other industries, such as offshore oil and gas, also have local power needs [17]. They are currently filling power needs with diesel power, but are looking to renewable energy as an alternative. While WECs provide a smaller amount of power than offshore wind turbines, the power can be primarily used for charging batteries for the local system power. Hybrid wind wave systems may be looked toward as a renewable energy of the future, but there are present challenges to the development of such systems.

5. Challenges

There are research challenges to further develop hybrid wind and wave energy systems. Wave energy converters have been in modern research and development since the 1970s, but WECs are in a much earlier development stage than offshore wind turbines [1,4]. There are still many types of WECs, and no design convergence. WECs must economically produce power in typical sea states and also survive in harsh storm conditions. These challenges add risk, complexity, and cost to hybrid wind wave systems in comparison to floating offshore wind turbines without WECs. Additionally, the power output of WECs is currently an order of magnitude smaller than wind turbines. WECs would ideally produce 1 MW each, but they are currently on the order of producing 100-500 kW [1] compared to offshore wind turbine capacity of 5-10 MW. Finally, more research is needed on offshore platform motion suppression of WECs. It has been shown that if not carefully designed, the difference in platform structural loading could be negligible or even worse than offshore wind systems. These challenges are the current focus of research in hybrid offshore wind and wave energy. Hybrid wind wave systems have many research challenges, but the research may dovetail with ongoing research of offshore wind turbine platforms.

6. Conclusion

Hybrid wind wave systems have potential to be a part of offshore wind energy of the future. The main benefit of combining wave energy with floating offshore wind is the platform motion suppression and local power needs. WECs can suppress platform motion both passively and actively through WEC control. Research and development of hybrid wind wave systems is still a relatively new research area. The W2Power and Poseidon case studies show the two hybrid systems that have reached ocean demonstration stages. Hybrid wind wave systems may add risk to offshore wind development, and further research is needed for advancements in this area. With research innovations, WECs could be combined with floating offshore wind to optimize power production and minimize structural loading of these systems.

References

[1] Cruz. Ocean Wave Energy. Springer International Publishing; 2008.
[2] Karimirad M. Offshore Energy Structures [Internet]. Cham: Springer International Publishing; 2014. 1–301 p. Available from: http://link.springer.com/10.1007/978-3-319-12175-8
[3] Gunn K, Stock-Williams C. Quantifying the global wave power resource. Renew Energy [Internet]. 2012;44:296–304. Available from: http://dx.doi.org/10.1016/j.renene.2012.01.101
[4] Pérez-Collazo C, Greaves D, Iglesias G. A review of combined wave and offshore wind energy. Renew Sustain Energy Rev. 2015;42:141–53.
[5] Perez-Collazo C, Greaves D, Iglesias G. Hydrodynamic response of the WEC sub-system of a novel hybrid wind-wave energy converter. Energy Convers Manag. 2018;171(March):307–25.
[6] Thiagarajan KP. A Review of Floating Platform Concepts for Offshore Wind Energy Generation. 2018;136(May 2014):1–6.
[7] Roy A, Auger F, Dupriez-Robin F, Bourguet S, Tran QT. Electrical Power Supply of Remote Maritime Areas: A Review of Hybrid Systems Based on Marine Renewable Energies. Energies. 2018;11(7):1904.
[8] Strategic Initiative for Ocean Energy (supported by Intelligent Energy Europe for a Sustainable Future). Ocean Energy: State of the Art. EU Proj Rep. 2012;79.
[9] Hanssen JE, Margheritini L, O'Sullivan K, Mayorga P, Martinez I, Arriaga A, et al. Design and performance validation of a hybrid offshore renewable energy platform. 2015;1–8.
[10] Legaz MJ, Coronil D, Mayorga P, Fernandez J. Study of a Hybrid Renewable Energy Platform: W2Power. In: Ocean, Offshore, and Arctic Engineering (OMAE). Madrid; 2018. p. 1–9.
[11] Haji MN, Kluger JM, Sapsis TP, Slocum AH. A symbiotic approach to the design of offshore wind turbines with other energy harvesting systems. Ocean Eng [Internet]. 2018;169:673–81. Available from: https://doi.org/10.1016/j.oceaneng.2018.07.026
[12] Kluger JM. Synergistic Design of a Combined Floating Wind Turbine - Wave Energy

Converter. Massachusetts Institute of Technology; 2017.

[13] Zhu H, Hu C. A Study on Control of Wave Energy Converter for Motion Suppression of Semisubmersible. IFAC-PapersOnLine. 2016;49(23):380–5.

[14] Borg M, Collu M, Brennan FP. Use of a wave energy converter as a motion suppression device for floating wind turbines. Energy Procedia [Internet]. 2013;35(0):223–33. Available from: http://dx.doi.org/10.1016/j.egypro.2013.07.175

[15] Muliawan MJ, Karimirad M, Gao Z, Moan T. Extreme responses of a combined spar-type floating wind turbine and floating wave energy converter (STC) system with survival modes. Ocean Eng [Internet]. 2013;65:71–82. Available from: http://dx.doi.org/10.1016/j.oceaneng.2013.03.002

[16] Kelly T, Dooley T, Campbell J, Ringwood J V. Comparison of the experimental and numerical results of modelling a 32-oscillatingwater column (OWC), V-shaped floating wave energy converter. Energies. 2013;6(8):4045–77.

[17] Haces-Fernandez F, Li H, Ramirez D. Assessment of the potential of energy extracted from waves and wind to supply offshore oil platforms operating in the gulf of Mexico. Energies. 2018;11(5).