A Review of The Combined Wind and Wave Energy Technologies

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ABSTRACT

The efficient development of wind and wave energy systems is a major concern; optimizing resources and developing mechanisms that minimize costs is a pressing challenge. It is with reference to this that we study a combination of wind and wave energy systems that. We will see that these systems offer some exciting avenues in reducing system-wide costs. In the ensuing passages we look at different options of combining existing wind and wave energy systems.

Keywords: *Wind energy, wave energy, floating islands, hybrid systems*

I. INTRODUCTION

A. *Background*

The two forms of energy that dominate the present day ocean energy market are offshore wind and wave [1, 2]. We have been able to develop an understanding of the kind of systems the two incorporate, as well as the potential and the various drawbacks they have to offer. There have been several examples in the recent past where these systems have been effectively employed to harness ocean energy.

Notwithstanding the several advantages promised by these two systems, we still need efficient mechanisms to ensure that they do not overburden the natural resources. It is clear that the development of off-shore wind and wave energy should be done in a manner that does not disturb the ecological balance [3]. For this, one of the primary concerns is related to the efficient utilization of natural resources. Another concern is to bring down the costs involved to make the projects practically feasible. It is in this context that the need for integration arises.

Combining wave and offshore wind energy is a relatively recent approach to tackle the problems highlighted above. The unique synergy effects offer a potential to reduce the cost of electrical energy from offshore units while increasing the quality of the delivered power to the grid. The combination also offers an opportunity to share infrastructures between the systems as well.

Presently, there is a restricted number of articles in the literature that can elaborate on the potential of combined wave and offshore technologies in a sufficient manner. While some of them look to analyze the resource utilization aspects of the hybrid approach [9–13], others look towards integrating the technology to grid systems, generating direct electricity [14, 15].

B. Objectives

In the following passages we look at the systems that are necessary to harness the combined potential of the two technologies, the principal advantages and challenges they have to offer, along with a case study on a recent approach developed by Peiffer and Roddier [6].

More precisely, we attempt to analyze the different alternatives for combining wave and offshore wind energy, to give a complete view of the possibilities and current limitations of these systems.

Our document is structured as follows: in section 2 we review the previous work done in this field. In section 3 we discuss the major technologies powering hybrid systems. In section 4 we look at a recent case study, and finally in section 5 we offer conclusions.

II. LITERATURE REVIEW

Some of the earliest work in the field of hybrid technologies was done by Francesco Fusco, Gary Nolan and John V.Ringwood [13]. They presented a methodology to assess the possible benefits of the combination of wind energy with the still unexploited, but quite notable, wave energy in Ireland. Their analysis of the raw wind and wave resources at certain locations around the coasts of Ireland shows how they are very less correlated on the South and West Coast, where the waves are dominated by the presence of high energy swells generated by remote westerly wind systems. They concluded that by integrating wind and waves in combined farms at these locations, it is possible to achieve a more reliable, less variable and more predictable production of electrical power. The resulting benefits are clear especially in the case of a relatively small and isolated electrical system such as the Irish one. In fact, high levels of wind penetration this case strongly increase the requirement of surplus capacity and cause a much lower efficiency for conventional thermal plants.

A seminal work covering different types of avant-garde hybrid technologies was concluded by Pérez-Collazo, C. et al [3]. It presented an ubiquitous analysis of the most relevant aspects related to combined wave and offshore wind energy systems. It developed the different areas related to these systems, aiming to establish a reference frame to be used in future research and developments. The different combined wave and offshore wind systems were reviewed that resulted in a novel classification based on the extent to which the wave and offshore wind technologies are linked. It distinguished three categories, co-located, hybrid, and island systems. Based on this classification, an extensive assessment of the different concepts was presented.

The presence of a combined resource together with the strong synergies existing between both technologies makes a compelling argument for combining wave and offshore wind energy to achieve a sustainable and rational exploitation of the offshore energy resources. Fundamental research was identified as crucial to test the validity, sustainability and integration of these combined systems; to also determine the extent to which these new or adapted WECs are suitable to be combined with current offshore wind farms.

Another work that takes a comprehensive approach is that of [12]. It considers the different aspects concerning the co-location of wave and offshore wind farms and presents a preliminary case study of a hybrid array. As a first step, it presented the issues in synergies and technology development of wave and wind energy systems. In the second phase, different alternatives to combine wave and offshore wind energy systems were presented. Finally, a case study analyzing three possible co-located farms was done. A number of development issues were highlighted as the main challenges for WECs to be integrated with offshore wind. These challenges represent some key research lines and cues which need to be addressed in recent years to realize co-located farms become a reality.

Another noteworthy paper that carried out an extensive analysis of the energy production of a hybrid wave-wind farm was that of [10]. The main objective of this work was to analyze the energy that could be obtained from a hybrid wave-wind farm located in an optimum area for the exploitation of both resources. The authors concluded that such a farm, consisting of offshore wind turbines and co-located Wave Energy Converters (WECs), would be instrumental in realizing the synergies between wave and offshore wind energy. They used data from a hind-cast database spanning 44 years, and investigated the seasonal variability of the hybrid farm's output. They discovered that the hybrid farm indeed constitutes an excellent approach to satisfying the energy requirements of Tenerife and most of the wave and offshore wind energy will be produced in summer mainly because of the high occurrence of winds and waves in the ranges for which offshore wind turbines and WECs are very efficient.

Stoutenburg et. al investigated the power variations of co-located offshore wind turbines and WECs along the California coast [15]. They used Meteorological wind and wave data from the National Buoy Data Center to estimate the hourly power output from offshore wind turbines and WECs at the sites of the buoys. The data set from 12 buoys consisted of over 1,000,000 hours of simultaneous hourly mean wind and wave measurements. It was found that at the buoys, offshore wind farms would have capacity factors ranging from 30% to 50%, and wave farms would have capacity factors ranging from 22% to 29%. Their analysis of the power output indicated that co-located offshore wind and wave energy farms generate less variable power output than a wind or wave farm operating alone. This was due to the low temporal interrelation of the resources and occurs on all time scales. Moreover, their analysis indicated that aggregate power from a co-located wind and wave farm achieves reductions in variability which is equivalent to aggregating power from two offshore wind farms approximately 500 km apart or two wave farms approximately 800 km apart. Combined wind and wave farms in California would have less than 100 hours of no power output per year, compared to over 1000 hours for offshore wind or over 200 hours for wave farms alone. Moreover, ten offshore farms of wind, wave, or both modeled in the California power system would have capacity factors during the summer ranging from 21% (all wave) to 36% (all wind) with combined wind and wave farms between 21% and 36%.

M. Karimirad [16] gauged the feasibility of combining a spar-type offshore wind turbine (inspired by Hywind) and a wave energy converter (inspired by Wavestar) by performing numerical simulations in operational conditions. The dynamic responses and power production of wind turbine and wave energy device are investigated for different power-take-off systems. Coupled/integrated aero-hydro-servo-elastic time domain dynamic simulations considering multi-bodies are applied in this paper. The results show that by choosing proper power-take-off system, it is possible to minimize the effect of WECs on the floating wind turbine and hence maintaining the power performance of the wind turbine while getting more power through wave energy device.

III. TECHNOLOGY

An important factor in combining two different technologies is the resulting synergies they share. This becomes significant in this case, because the combined wind and wave energies offer a great development potential. Concisely, these combined systems can be classified on the following grounds as proposed in [3]:

- the technology used
- required depth of water(shallow, transition, or deep)
- location relative to the shoreline (shoreline, nearshore, offshore)

- degree of connectivity between offshore wind turbines and wave energy converters (co-located, hybrid, and island systems)

Out of the four, we look at the systems defined by the degree of connectivity, primarily because they make up a significant categorization by themselves, as described by Pérez-Collazo, C. et al. [3] in their seminal work.

A. Co-located systems

This is perhaps the simplest, and the most natural option at the current stage of Fundamentally, these systems combine an offshore wind farm with a wave energy converter array. In other words, these systems consist of independent, isolated systems that are brought together. These systems share several resources like marine area, grid connection, operation and maintenance equipment, etc. Usually,such systems are based on an offshore wind farm, either bottom-fixed or floating. Moreover, these systems do not require any new technology developments.
These system can be further classified into independent arrays and combined arrays.

a). Independent arrays

These systems have separate offshore wind and wave farms, and occupy separate marine areas. But the distance between them is such that they are able to share the same electric grid connection along with other installations. A schematic representation of an independent system is shown as follows.

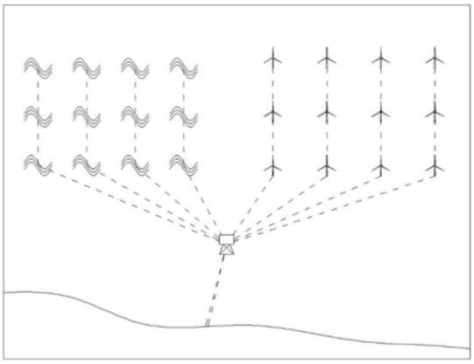

Figure: Schematic of a co-located independent array [3] development of hybrid technologies.

b). Combined arrays

Differing from independent arrays, in this case the offshore wind and wave devices are developed in the same marine area and they share various kinds of infrastructures, in effect, making them behave like single, unified hybrid system. Hence the name single array.

Likewise, combined arrays can be further classified into three categories:

- Peripherally Distributed Array (PDA)
- Uniformly Distributed Array (UDA)
- Non-uniformly Distributed Array (NDA)

The PDA is designed to keep the wave energy converters around the perimeter of the array, in such a way that they follow the direction of the wind, and hence serve as wave shields, protecting the wind devices from the turbulent waves, and consequently, reducing the amount of energy intercepted by the inner section. In a UDA, the wave energy converters are uniformly distributed among the gaps of the wind energy turbines. The NDA does not follow any set patter, and has an uneven distribution of wave energy converters among the wind turbines.

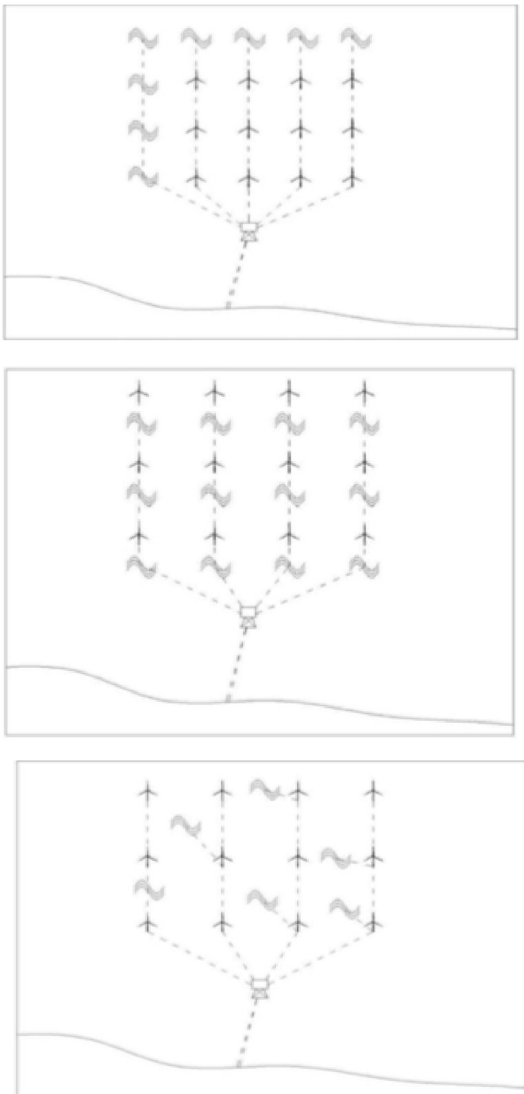

Figure: (From top) Schematic of PDA, UDA, NDA [3]

B. Hybrid systems

A hybrid system combines a wind turbine and a wave energy converter on the same structure.Hybrid systems can be further classified into bottom-fixed, useful for shallow or transitional waters and floating type, appropriate for deep waters.

a). *Bottom-fixed hybrids*

In effect, bottom-fixed hybrids follow naturally from the current systems used by the offshore wind industry. These systems can be modified to accommodate a wave energy converter.

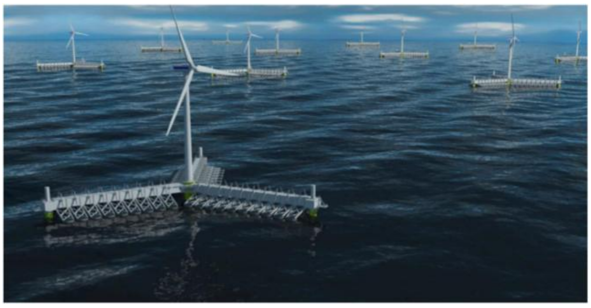

Figure 3: Artist's impression of a bottom-fixed hybrid [3]

Essentially, a bottom-fixed hybrid can be developed by integrating a wave energy converter into an existing offshore wind turbine.

b). Floating hybrids

The floating hybrid is a relatively modern concept that has come into perspective because of the emerging floating offshore wind prototypes, with a considerable number of developers constructing floating substructures that combine offshore wind turbines with wave energy converters.

In the practical world, there have been two EU funded projects, MARINA and TROPOS that dealt precisely with these hybrid systems.

In general, hybrid systems are based on the concept of offshore multipurpose platforms.

C. Island systems

The last category of combined wave and wind energy technologies is island systems. These systems, just like hybrid systems, are based on the ideas of offshore multipurpose platforms. However, unlike hybrid systems, these island systems are usually much larger and integrate the combined exploitation of more than two marine resources on the same platform.

Figure: WindWaveFloat,a floating hybrid wave-wind device (courtesy of Wikimedia [5])

Island systems can be again divided into either artificial or floating islands.

a). Artificial islands

Artificial islands can be developed as platforms for large-scale electricity storage, MRE converters, and other marine activities. A recent and useful concept of this type is that of the Kema Energy Island for Large-scale electricity storage from the Dutch DNV KEMA Consulting.

b). Floating islands

Floating energy islands are large floating multipurpose platforms, and are similar to artificial islands, except on the grounds of capacity and size. These systems are usually of smaller dimensions than artificial islands but larger than most vessels.

IV. CASE STUDY (WIND-WAVE-FLOAT)

A. Introduction

Antoine Peiffer and Dominique Roddier Antoine Peiffer and Dominique Roddier have reported the design of a hybrid device based on combining a wave energy converter on the WindFloat structure. Their seminal paper summarized the numerical modeling and experimental testing that were performed to integrate an Oscillating Wave Surge Converter on the Wind-Float structure [6]. Several further studies have been carried out to investigate the possible solutions by appending different wave energy converters onto the WindFloat device. We look at two such Oscillating water columns and spherical-point absorber devices have been tested.

In general, this hybrid floating wave-wind concept integrating the wave energy converters and the floating WindFloat wind turbine is christened as WindWaveFloat. In design, the WindFloat is a 3-legged floating structure supporting a very large wind turbine, that produces energy greater than 5 MW [6]. The three legs are placed in such a manner that they form an equilateral, and heave plates are fitted at the base of the column, increasing the mass of the total structure. The structure is moored to the seabed, and an electrical cable connects the turbine to the shore. The WindWaveFloat represents an enticing solution for harvesting energy from offshore wind and wave renewable resources.

B. Study considerations

In this section we look at some of the technical details of WindWaveFloat.

In the present stage of floating wind structures, there have been several public demonstrations in the recent past, with different devices being at different stages of development. The HyWind project of Statoil, that features a Siemens 2.3 MW offshore wind turbine has been in use off the coast of Norway since 2009[8]. Principle Power deployed the WindFloat off the coast of Portugal in 2011; featuring a Vestas 2 MW offshore wind turbine.

The WindFloat essentially allows integration with any commercially available, horizontal axis offshore wind turbine. However, other floating support structures may rely on custom turbine designs.

We borrow from the design suggested by [6]. In its basic form, the WindWaveFloat design is based on the power-take-off (PTO) solutions that are directly mounted onto the WindFloat. Using this structure as the basis for an integrated wind-wave energy conversion device offers several opportunities. However, the use of the floating wind support structure as the reference frame for wave PTOs may result in larger motion due to the forces resulting from energy extraction. Therefore, a proper control procedure is needed. One must also optimize the final design to enable an efficient and reliable power production.

Technically, the WindWaveFloat consists of 4 mooring lines, two on column 1, which carries the turbine, and one on each other column. Each line is made of 3 sections: a 3-inch chain at the fair lead, a 5-inch polyester, and another 3-inch chain to the anchor at the bottom. A weight is placed between the upper chain section and the polyester rope to control the tension. The pretension on the mooring lines is 535kN. The displacement of the support structure is 4832 metric tons.

a). Oscillating Water Column

In an oscillating water column (OWC) water enters into a chamber filled with air. As waves pass, the amount of water in the chamber rises and falls like in a piston, thereby sequentially compressing and decompressing the air inside. These positive and negatives changes in pressure result in the ability to direct the air through a bi- directional turbine coupled with an electric generator. A Wells turbine is a common choice for this type of application.

Figure: WindWaveFloat featuring Oscillating Water Column Systems [6]

In this case, the priority is preserving the stability performance of the original WindFloat design, so the chambers are built around the columns that are not responsible for supporting the wind tower and turbine, and for design simplicity's sake extend only 240 degrees around the column, avoiding truss-connecting points on the column.

The effect of the OWC system on support structure motions needs to be understood for both how it might affect performance of wind turbine and how it might affect the performance of the wave energy device.

b). Spherical Point Absorber

The SWEDE (Spherical Wave Energy DEvice) is a spherical point absorber situated in the centre of the structure and attached to the WindFloat columns by three springs and dampening elements. A point absorber is a floating system that absorbs energy in all directions through its movements on the waters surface. A point absorber is usually deigned to resonate so that its harnessed power is maximized.

Figure: WindWaveFloat featuring SWEDE [6]

A spherical floater responds well to heaving with very little pitch motion. The single device SWEDE is a spherical floater installed at the centre of the WindFloat support structure. The floater is attached to the column of the WindFloat by using three lines representing the power take-off system.

C. Economic considerations

By adding a WEC to the structure, the overall economics of the project can be improved. The cost of the WEC alone needs to be less than the energy it produces. However, by sharing both mooring and power infrastructure, the WEC economics become highly advantageous over a farm of WEC alone. WindWaveFloat, along with other innovations in the field of multi-national interlinked offshore-grids, osmotic power projects and offshore energy storage [7] are needed to make a strong impact in the energy space. Ocean energy offers the benefits of significant resources without competing for land use, but blatantly suffers from projected high operating, installation and maintenance costs. The WindWaveFloat concept offers the potential ability to increase the energy production from each floating support structure by approximately

30%. For example, wave energy converters installed in a WindFloat, a floating support structure for large offshore wind turbines, could potentially increase each unit's nameplate capacity from 5 MW to 7.5 MW without a need for additional cabling, space or permits. The ultimate result could lead to the reduction of levelized energy costs by approximately 25%, increase in the overall capacity factor by approximately 10% as compared to the wind only generation, and enhanced stability of the electrical power delivered to the grid.

D. Indian context

The potential of wave energy along the 6000 Km of coast is about 40,000 MW. Primary estimates indicate that the annual wave energy potential along the Indian coast is between 5 MW to 15 MW per meter, thus a theoretical potential for a coast line of nearly 6000 KW works out to 40000-60000 MW approximately. Similarly, India has an estimated 127 GW of offshore wind power potential, mostly off the coasts of Tamil Nadu, Gujarat, and Maharashtra.

Clearly, the two resources abound here, so in terms of brute numbers, combined wave-wind systems have a lot of scope in India. Despite these hopeful signs, we are still far from developing a hybrid offshore system. At the moment, India lacks even the basic infrastructure for a proper offshore wind farm. We do not have a single offshore wind facility that can be combined with existing wave energy conversion systems. Therefore, we have a long way to go before being able to actually implement combined wind-wave systems.

V. CONCLUSIONS

In this paper we have attempted to present an overarching analysis of hybrid wind and wave energy technologies. The main point in combining a wind turbine concept with a WEC concept is to decrease the finished cost of electricity in a long-term perspective. No matter from which side we start, from wave energy or from wind power. The goal is clear which is maturing the offshore renewable energy. The idea of adding a wave-energy device to a floating support structure of a wind turbine is increasing the stability, damping the structure motion by extracting the wave energy and, hence, increasing the produced wind power while taking the wave power, simultaneously. However, as we have seen, the present status of the technology is mostly restricted to prototypical designs. We are still far from pushing this technology into the commercial arena. But the very fact that this sector is less developed than other renewable energy industries presents both opportunities and challenges. The lack of an established industry structure can make entry into the market uncertain for newcomers. However, this lack of structure also means that companies are potentially more able to create and take opportunities than is possible in other parts of the energy industry that are developed and more mature

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