

# Research on combined power generation of wave energy and wind energy

Beining Ru<sup>1\*</sup>

<sup>1</sup>School of New Energy, Nanjing University of Science and Technology, Jiangyin, JiangSu, 214400, China

**Abstract.** With the continuous growth of global energy demand and the increasingly severe environmental pollution problem, it has become particularly urgent to find clean and sustainable alternative energy sources. This article examines the possibilities for offshore wind and wave energy as renewable energy sources in detail and discusses the strategy and technology involved in generating combined power from them. An evaluation of the offshore wind energy and wave energy resources is done first, and then their distribution is briefly discussed. The research on wind and wave integrated energy-generating technologies is covered in this article. It also covers the fundamental technologies of complementary power generation platforms for the wind and waves, integration feasibility, shared array cost modeling, and development status. The technical research section analyzes in detail the control system design, wind and wave complementary energy supply devices, fixed wind turbine basic wave energy devices, and the creation of newly developed platforms for generating combined electricity from waves and wind. Finally, the article highlights the significance of technological innovation, optimized scheduling, and system integration, looks forward to the future development path of wind and wave-integrated energy generation, suggests specific research avenues, and acknowledges the unavoidable trend of industrialization and marketization. Although wind and wave combined power generation technology faces challenges in maturity and stability, as well as high research, operation and maintenance costs, it plays an important role in promoting energy structure transformation and responding to climate change.

## 1 Introduction

Human society's need for energy is expanding as a result of industrialization and modernization's quick development. But in addition to causing conventional fossil energy to become scarcer, over-extraction and use of non-renewable resources like coal, oil, and natural gas have also resulted in significant environmental pollution issues. Therefore, finding clean alternative energy and reducing dependence on traditional energy has become a major global issue. Renewable energy, such as solar energy, wind energy, hydropower, biomass energy, etc., is clean and sustainable, and can effectively reduce greenhouse gas emissions and slow down climate warming. Two renewable energy sources with significant development potential are offshore wind and wave energy. Generally, the wind speed and direction are steadier at water than on land, which makes offshore wind power have higher power generation efficiency and larger installed capacity; wave energy uses the energy of the fluctuations on the ocean surface and possesses a broad dispersion and a high energy density. Offshore wind and wave energy when coupled to generate electricity can accomplish energy complementarity, increase the stability and efficiency of energy use, lower the cost of power

---

\*Corresponding author: [rubeining@njust.edu.cn](mailto:rubeining@njust.edu.cn)

generation, and lessen reliance on a single energy source. The goal of this article is to provide new perspectives on the energy problem and environmental challenges by analyzing the strategy and technology of producing combined offshore wind and wave power. This article will cover the evaluation and present status of offshore wind and wave energy sources, the development of wind and wave integrated energy generation technology, the technical analysis of wind and wave integrated energy generation devices, and the wind and wave integrated energy generation's future development path.

## **2 Assessment and status of wave energy resources and offshore wind energy resources**

### **2.1 Wave energy resource assessment and status**

The energy found in the waves that the wind creates in the water is known as wave energy. Due to the wide area of the ocean, the distribution of wave energy is also very wide. The regions with the highest wave energy resources are found in the westerly belt at higher latitudes, such as the North Atlantic, North Pacific, and Southern Ocean, according to global geographic circumstances and climatic features. Furthermore, there are regions in the deep water that have abundant wave energy resources, but there hasn't been much development or use of them because of the difficulties of mining and the distance from shore. Seasons also have an impact on how wave energy resources are distributed. Since waves are simpler to create and the wind is greater in the summer, the wave energy resources are generally richer in the summer; in the winter, when the temperature is lower, the wind is weaker and the waves are less. Furthermore, the bottom topography has an impact on wave energy richness. Because the water depth near the coast is shallower and it is simpler to transform kinetic energy into wave energy, The nearshore seas have more abundant wave energy resources than the open sea. By encouraging wave collection, which produces relatively rich wave energy resources, islands, and peninsulas also aid in the production of higher waves. In addition, factors including wind direction and strength, ocean currents, human activities, and climate change will affect the distribution of wave energy resources. Zheng summarized the previous research on the distribution of global ocean wave energy resources, pointing out that the northeastern North Atlantic Ocean, northeastern Pacific Ocean, west coast of North America, southern coast of Australia, southwestern coast of South Africa, and so on are the primary locations of the global wave energy enrichment regions<sup>[1]</sup>. Taking into account factors such as the size of the wave energy flux density, energy level frequency, frequency of effective wind speed and available wave height, long-term change trend and stability of energy flux density, total energy reserves, effective reserves, and technological development, an exploratory classification and systematic assessment of wave energy resources in the oceans around the world are conducted.

At present, the main wave energy power generation devices include oscillating water column generators, point suction generators, buoy generators, dam generators, trough devices, compressed air generators, etc. Wave energy power generation technology development will no longer solely concentrate on research on single device power generation; rather, multi-degree-of-freedom, array power generation, multi-energy complementary coupling power generation, as well as multi-functional integrated platform utilization will all gain importance. Multi-degree-of-freedom devices improve wave energy capture capabilities by releasing device freedom, while array power generation achieves large-scale deployment of power generation devices through modularization. Furthermore, a popular issue in the field of marine energy power production study nowadays is the combined wave and wind energy generating for electricity, which contributes to increasing the rate of utilization of offshore

energy and achieving global emission and carbon reduction. It is expected that with the development of technology and the reduction of costs, wave energy power generation will occupy a certain position in renewable energy. By 2025, the global wave energy power generation market is expected to reach tens of billions of dollars, and there is huge room for development.

## **2.2 Offshore wind energy resource assessment and status quo**

Compared with onshore wind energy, offshore wind energy has significant advantages. Offshore wind power generation generates more energy because of the tiny amount of friction on the sea surface, which causes the wind speed and direction to be steadier than on land. Offshore wind power has relatively little interference with the terrestrial ecological environment and has low noise and visual impact. Offshore wind power does not occupy precious land resources and is particularly suitable for areas with tight land resources. In addition, offshore wind power is close to coastal cities and industrial areas, which facilitates the transmission and use of electricity and reduces transmission losses. At present, global offshore wind power is developing rapidly, with an average annual growth rate of about 21%. Globally, the North Sea coast of Europe, the coast of East Asia, and the coast of North America are the regions with the most offshore wind energy resources. As two forms of marine renewable energy, wind and wave energy naturally complement one another. On the one hand, areas with abundant wind resources also frequently have abundant wave resources. The combination of the two can effectively improve energy utilization and energy output per unit sea area. On the other hand, wind power has strong volatility, and its energy absorption is not stable enough, while wave energy can provide a relatively stable energy supplement. Because the two energy sources complement each other, the strain on the power grid is balanced and the issue of an unstable power supply brought on by variations in a single energy source is lessened. Infrastructure sharing is another possibility for cooperative electricity generation. Offshore floating wind turbines are not only subject to aerodynamic loads acting on wind turbines and hydrodynamic loads of waves on wind turbine platform foundations but also to loads acting on wind turbine platforms by mooring systems. Wind-wave joint power generation devices can share mooring, electricity, and other facilities to reduce costs.

## **3 Research progress of wind-wave joint power generation technology**

### **3.1 Key technologies of floating wind-wave complementary power generation platforms**

Liu Jiahao et al. discussed the current development status of wind-wave joint power generation devices, introduced key technologies of floating wind-wave complementary power generation platforms, such as platform stability and layout optimization, proposed some current problems, such as poor stability and difficulty of distributed array technology, and looked forward to the prospects of developing multi-energy complementary power production in the deep sea<sup>[2]</sup>. In response to the stability problem, a new tension leg-anchor cable combined mooring system is proposed, which can better suppress the dynamic response of the whole structure of floating wind turbines. As for the distributed array technology, the optimization schemes such as circular array arrangement, joint power generation, and optimization method based on uniformly distributed array, integrated system of circular array wave power generation device are summarized, as well as the difference between the benefits

brought by mixed and single arrangement of multiple arrangement modes, and multiple arrangement mode hybrid arrays that can make up for the shortcomings of single arrangement mode are sought.

### **3.2 Viability of integrated wind and wave power generation**

PÉREZ-COLLAZO C et al. spoke on the feasibility of combining the wave and wind power industries to lower costs, the benefits of offshore wave and wind power, various combinations for the two, and technical specifics<sup>[3]</sup>. Wave and offshore wind power combined is a relatively new system, so it lacks a thorough classification system. To address this, the author proposed a corresponding classification method based on the type of infrastructure and the degree of technology integration, which lays the groundwork for an overview of various concepts. As renewable energy sources, offshore wind power and wave power have similar sea use requirements and similar supporting structures. The effectiveness of using offshore space can be increased by the combined growth of wind and waves. Simultaneously, because of the high energy flow density in the surrounding areas and the cyclical variations in wind and wave energy, they have good synergistic impacts on development and utilization. This synergy can not only reduce costs but also improve the stability of power generation.

Wind-wave combined power generating technologies come in a wide variety; however, the combination of vertical axis wind turbines with floating wave energy power production devices is the primary focus of the study. A technological integration plan must take into account variables including the hydrodynamic performance of array floats, the control strategy, the transmission characteristics of the hydraulic system, and the performance of vertical axis wind turbines. In order to perform wind and wave energy connection at the hydraulic system end, it is also critical to consider how to optimize the energy integration of the system by miniaturizing and modularly grouping hydraulic motors and generators.

### **3.3 Cost model of shared arrays**

CLARKCE et al. solved the problem that most of the synergies generated by shared arrays were not included in the cost model by developing a cost model for shared arrays of floating offshore wind power technology and wave energy converters (WECs), and illustrated the use of the cost model through case studies<sup>[4]</sup>. The results show that floating wind power-wave energy shared arrays have advantages over using only WECs or only floating wind power. In addition, the gaps and uncertainties in the research are pointed out so that they can be simplified when the model is improved in the future. The cost model can comprehensively evaluate the economic feasibility of wind-wave combined power generation projects, including initial investment, operating costs, maintenance costs, etc. Through cost model analysis, the design of wind-wave combined power generation systems can be optimized, and the most cost-effective technical solutions can be selected. In addition, the cost model helps to identify and quantify project risks and provides a basis for risk management.

### **3.4 Current status of wave-wind combined power generation**

According to McTiernan et al.'s evaluation of the state of the art for wave-wind combined power generation, wave energy is currently less developed than offshore wind energy<sup>[5]</sup>. Wave energy generators can protect offshore wind turbines from the impact of waves, control operations to reduce system loads, and generate supplementary electricity for offshore wind turbines. It is also claimed that research and development on hybrid wind-wave systems is mostly focused on floating offshore wind turbines. Additionally, two demonstration-scale marine hybrid wind-wave systems, the Poseidon wind-wave system, and the W2Power

system are analyzed as case studies. Wave and wind energy can complement one other's advantages through cooperative power generation, reduced power-producing costs, and increased energy efficiency, despite their distinct technological limitations and problems.

## **4 Technical research on hybrid power-generating gadget using wind and wave energy**

### **4.1 Control system design and implementation**

The design and implementation of the control system of a hybrid power-generating gadget using wind and wave energy is a complex engineering task, which requires comprehensive consideration of hardware configuration, software design, control strategy, and other aspects. By continuously optimizing and improving the control system, the energy capture efficiency and stability of the device can be further improved, and the development and application of marine renewable energy technology can be promoted. Yang et al. developed a control strategy for the offshore wind and wave complementary energy production control system after researching and evaluating the control system of the offshore wave energy and wind energy complementary power generation platform<sup>[6]</sup>. Based on this strategy, they developed the offshore wind and wave complementing power-producing platform control system. The research covered the following topics: the goals and structure of the offshore wind and wave complementary power generation control system; the control strategy of the energy management system; the plan for remote transmission and status monitoring of energy generation equipment; the software and hardware design; and the final software and hardware design and construction of the offshore wind and wave complementary power generation control system.

### **4.2 Complementary energy supply device for wind and waves**

The supplementary power-generating device that generates electricity from wind and waves may also be integrated with other underwater equipment to provide them with a direct energy supply. This can help to increase the efficiency with which marine renewable energy is utilized and decrease electricity loss during transit. The lifting film seawater desalination device designed by Minghui et al. incorporates a wave energy and wind energy complementary energy supply system [7]. An energy capture device, a mechanical energy synthesis device, and a power production device are used to provide the energy needed for saltwater desalination. The energy collection device is composed of a vertical axis wind turbine and a vertical swing float wave energy power generation device. This device realizes multi-level energy utilization and achieves the purpose of energy saving and environmental protection.

### **4.3 Fixed wind turbine foundation wave energy device**

Fixed wind turbines usually refer to wind turbines installed in offshore areas with the bottom fixed on the seabed. Based on this, a wave energy device is added in order to simultaneously create power utilizing wave and wind energy. Its fixed construction gives it more stability and the capacity to endure stronger winds and waves than other wind and wave combination usage technologies. Based on a fixed four-legged pipe frame offshore wind turbine foundation, Gao et al. presented an oscillating float wave energy device [8]. They also examined the impact of the wave energy device on the wave field around the wind turbine foundation and summarized the law. A single-side float has a higher energy absorption rate

and a more noticeable shielding effect on the wave field than a single front float, according to the study, which provides a theoretical foundation and design specifications for offshore wave and wind interaction. Appropriate floats should be chosen in accordance with the wave height and period conditions of a particular sea area.

#### **4.4 Design of a new wind-wave integrated energy generation platform**

The load distribution and overall stability of the entire structural system are affected by the interference effects between cylinders of various scales in the buoys, columns, and floats of the wind-wave combined power production structure floating platform. These effects cannot be disregarded. In order to design a new wind-wave integrated energy generation structure system appropriate for China's South China Sea trend, Zhao et al. summarized the research findings on the selection and hydrodynamic performance of wind-wave integrated energy generation systems both domestically and internationally [9]. They also examined the hydrodynamic load characteristics of the new wind-wave integrated energy generation platform and analyzed the water flow field process inside the platform.

#### **4.5 Differential coupling complementary energy generating system using wind and waves**

The differential coupling complementary power generation system uses differentials and other similar mechanical devices to coordinate the speed difference between wind energy and wave energy conversion devices to ensure the continuity and efficiency of the energy conversion process. Shang Jichang and others proposed a proposal to couple wind and wave energy using a differential planetary gear mechanism in an effort to address the problem of offshore wind-wave complementary energy generation systems' unsteady output power and low coupling efficiency [10]. They have also modeled and calculated the working performance of this scheme. The device regulates and transmits energy through hydraulic components, reducing fluctuations and losses in energy transmission, and thereby improving the energy recovery efficiency of the overall system.

### **5 Future development direction of wind and wave-integrated energy generation**

#### **5.1 Research hot spots and trends**

Wave and wind energy are mutually dependent and complementary. The "dual carbon" aim and the promotion of marine energy usage may be accomplished by the achievement of integrated combined power generation of wind and wave energy. Most research papers focus on vertical-axis wind turbines and oscillating float wave energy combined power generation devices. The equipment frequently has stability issues as a result of the various influences of wind, waves, and ocean currents. Vertical axis wind turbines offer the benefit of directional stability under inertial force and no requirement for yaw control over horizontal axis wind turbines. Oscillating float technology has several benefits over other wave energy generating methods, including an easy-to-maintain structure, cheap cost, and high operational efficiency. Additionally, the design of multi-degree-of-freedom devices will be more adaptable, dependable, and efficient due to the ongoing development of new materials, procedures, and technologies. Multi-degree-of-freedom devices allow wind turbines or wave energy conversion devices to move in multiple dimensions, thereby more effectively capturing and utilizing wind and wave energy. Arrayed power generation technology combines multiple

wind turbines or wave energy conversion devices into a large power generation system in a certain arrangement. This arrangement can optimize the energy output and operation and maintenance costs of the entire system. Arraying can not only increase the scale of the system and improve the power generation capacity, but also reduce the dependence on the performance of a single device through the synergy between devices and improve the stability and reliability of the entire system.

## 5.2 Prospects for commercial applications

China has created several complementary combined power production devices in recent years, including wind-wave, wind-tidal, and wind-solar energy. The creation and use of these devices demonstrate that the technology for generating combined electricity from waves and wind is currently capable of practical use. The industry as a whole, however, believes that the development and use of combined wind and wave power production technology is still in its infancy and needs more innovation and optimization in technology. One significant use of wind and wave combined power generating technology is the floating wind and wave complementary energy production platform. One of the essential technologies of these systems is platform stability, which also serves as the primary area of focus for researchers studying platforms that generate complementary power from waves and wind. In addition, the design, construction, operation, and maintenance of deep-sea platforms are also current problems. Therefore, in terms of platform stability, and operation and maintenance technology, wind and wave integrated energy generation technology still needs further research and breakthroughs.

As the global demand for clean energy continues to grow, wind and wave combined power generation, as green, environmentally friendly, renewable, and pollution-free new energy, will show huge market potential, promote the transformation and upgrading of the global energy structure, and gradually replace the status of traditional fossil energy. Countries all around the globe have implemented a variety of policies to encourage the development of clean energy in an effort to achieve sustainable development and address climate change. For instance, the Paris Agreement encourages the transformation of energy, shifting away from traditional fossil fuels like coal, oil, and natural gas and toward cleaner, renewable energy sources; it also supports and encourages the development, application, and promotion of renewable energy sources like wind, solar, and hydropower, increasing their share of the world's energy structure; and it fosters innovation and the advancement of clean energy technology, particularly the development, application, and storage of critical technologies like carbon capture and storage (CCS) and energy storage. With the support of policies, wind and wave complementary integrated energy generation technology will enter a new period of rapid development. At present, the world's advanced wave energy generation devices include the Wavegen Limet oscillating water column device, Pelamis wave energy converter, Seagen tidal stream turbine in the UK, Pico energy generation device in Portugal, China's "Nankun" megawatt floating wave energy generation device, "Huaqing" pneumatic wave energy generation device, "Jueku" wave generator, etc. In the future, the industrialization and marketization of wind and wave complementary integrated energy generation technology will become an inevitable trend.

## 5.3 Future research directions

Future research on wind and wave integrated power production, as a cutting-edge clean energy technology, is primarily focused on the following areas. With the objective to increase the capacity and power production efficiency of individual units, the first technological breakthrough in multi-energy complementary coupling power generation is the creation of

new and more effective wave and wind energy conversion devices. Create a novel kind of integrated wind and wave power generating platform that can support both wind turbines and wave energy conversion devices simultaneously, particularly for the use of both wind and wave energy in deep sea environments and harsh climate conditions. Resources like wind and wave energy may be precisely predicted and evaluated with the use of big data and artificial intelligence technologies. These technologies can also give data assistance for the best possible scheduling of the system. The stability, durability, and economy of the platform are the keys to its design. Environmental conditions, operation, and maintenance requirements of different sea areas need to be taken into consideration. Intelligent control systems can be introduced to realize real-time monitoring, prediction, and adaptive control of wind and wave integrated energy generation systems, improving the system's stability and reliability. In order to ensure stable system operation and maximize the use of clean energy sources like wind and wave energy, the second step is to optimize scheduling and system integration. This involves researching grid-connected scheduling and optimization technologies of wind and wave integrated energy generation systems and using energy storage technology to balance power supply and demand and address the intermittent and volatile issues associated with these sources of energy. attain the full utilization and configuration optimization of marine renewable energy, such as wind and wave energy, by studying the energy transmission and distribution technologies between systems; accomplish the seamless integration of wind and wave combined energy generation systems with the current power grid system to ensure the compatibility and stability between systems; assess and maximize the integrated wind and wave energy generating system's economic efficiency, lower the system's installation, operating, and maintenance costs, and increase its financial gains. At the same time, consider the influence of policy incentives and market mechanisms to provide strong support for the investment decision-making and operation strategy of the system.

## 6 Conclusion

This article's main topics are the assessment and current state of offshore wave and wind energy resources, as well as the advancements in the study and technical applications of wind and wave-integrated energy generation. It also highlights the technology's enormous potential and prospects, as well as its crucial role in displacing conventional energy, lowering global pollution, reducing climate change, and fostering innovative energy structures. However, the current research, technology, operation, and maintenance expenses are expensive, and the maturity and stability of wind and wave combined power production technologies are relatively low, which presents a significant challenge to researchers. Future research should focus on technological innovation, such as the development of efficient conversion devices and intelligent control systems, as well as the optimization of system integration, and the use of big data and artificial intelligence technologies for resource forecasting and system scheduling. To address the issues of intermittent and stable power generation, energy storage technology should be prioritized. Economic evaluations should be carried out to maximize project benefits, and the influence of market mechanisms and policy on investment and operation strategies should be taken into account. All of these steps will help to accelerate the industrialization and commercialization of complementary power generation technologies for wind and waves and further optimize the world's energy structure.

## References

1. C. Zheng. Prospects for the development of wave energy and offshore wind energy resources. *Journal of Subtropical Resources and Environment*, 4, 40-6 (2013).
2. J. Liu, P. Jiang. A review of the development of wind-wave energy complementary power generation technology. *East China Science and Technology*, 9, 54-6 (2022).
3. C. Perez-Collazo, D. Greaves, G. Iglesia. A review of combined wave and offshore wind energy. *Renewable and Sustainable Energy Reviews*, 42, 141-53 (2015).
4. C. E. Clark, A. Miller, B. Dupont. An analytical cost model for co-located floating wind-wave energy arrays. *Renewable Energy*, 132, 885-97 (2019).
5. K. L. Mctiernan, K. T. Sharman. Review of Hybrid Offshore Wind and Wave Energy Systems; proceedings of the North-American-Wind-Energy-Academy (NAWEA) International Conference on Future Technologies in Wind Energy (WindTech), Amherst, MA, Oct 14-16 (2019)
6. W. Yang. Research and design of control system for offshore wave energy and wind energy complementary power generation platform [D]; North China Electric Power University (Beijing) (2015).
7. H. Ming, L. Zhang, F. Liu, et al. Wave energy and wind energy complementary energy supply lifting membrane seawater desalination device. *Hebei Agricultural Machinery*, 11, 44-5 (2019).
8. R. Gao, H. Shi, J. Li, et al. Experimental study on a physical model of wave energy device based on the fixed wind turbine. *Acta Energiæ Solaris Sinica*, 44, 454-60 (2023).
9. Y. Zhao, S. Ke, Y. Yuan, et al. Multi-scale flow field evolution and load characteristics of buoy-column-float of a new wind-wave combined power generation floating platform. *Acta Energiæ Solaris Sinica*, 44, 370-9 (2023).
10. J. Shang, Z. Deng, B. Wang, et al. Performance analysis of differentially coupled wind-wave hybrid power generation system. *China Offshore Platform*, **38**, 11-6 (2023).