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The Design of Wave-Powered Floating Composite Panels and Self-Disassembling Flexible Connectors

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Abstract: *Wave energy, a marine renewable mechanical energy source that is widely distributed and requires relatively basic conversion devices, has become a critical energy source for remote offshore regions due to the increasing prevalence of energy shortages. The mechanical energy conversion efficiency and quality are diminished when the pendulum-like motion amplitude of existing monolithic plate-type wave energy converters is restricted by rigid fixed connections during dense deployment. A self-disconnecting flexible connector and a suspended composite panel for arrayed wave power generation that incorporates this connector are proposed in this study. Two parallel conical columns with their large ends facing each other constitute the self-disconnecting flexible connector. The main flexible connecting strip connects the large extremities of the two columns at both ends. In contrast, the bottom flexible connecting strip corresponds to each column individually, enabling its two ends to be detachably connected to the large and small ends of the columns, respectively. Each centrally positioned floating wave power generation module within the arrayed wave power generation floating modular unit is connected to contiguous modules via a self-disassembling flexible connector at both ends. This satisfies emergency rapid assembly requirements while establishing stable, flexible connections among multiple floating wave power generation modules. It offers technical assistance for the centralized and efficient operation of wave energy generation devices.*

Keywords: *Array-Type Wave Power Generation Floating Assembly; Aelf-Disconnecting Flexible Connector; Wave Energy Generation Device; Flexible Connection; Emergency Assembly*

1. Introduction

Wave energy has attracted the attention of a broad spectrum of society as energy shortages become more prevalent. Wave energy, a type of mechanical energy, is a high-quality resource within ocean energy sources that also facilitates the development of relatively straightforward energy conversion devices. Wave energy's enormous reserves are substantial, despite its low energy flux density. Wave energy potential can reach 30–70 kW/m² in regions such as the mid-latitude zones (30–40°) along the eastern coasts of the Pacific and Atlantic Oceans, with some areas exceeding 100 kW/m², assuring a sufficient total exploitable energy reserve. The peak wave energy is available during the winter months, effectively alleviating seasonal pressures on energy consumption. In regions such as the mid-latitude zones of the Pacific and Atlantic Oceans (30–40°N), wave energy can reach 30–70 kW/m², with some locations exceeding 100 kW/m². This ensures that there are substantial exploitable energy reserves. The challenge of enormous winter energy consumption is effectively alleviated by the highest wave energy potential that winter offers. Wave power is the most widely distributed renewable energy source in the ocean and can be utilized as an energy source in remote offshore areas [1].

An energy capture system, a secondary energy conversion system, and a tertiary energy conversion system are the typical components of wave power generation devices. There are three primary varieties of wave power devices: oscillating water column, oscillating body, and wave-rider, all of which are classified according to the energy capture system. Wave energy-capturing devices are perpetually exposed to seawater, which renders them susceptible to corrosion and necessitates a brief operational lifespan. Furthermore, marine environments, climate, water quality, and other factors are relatively intricate and contain a multitude of unstable elements. Additionally, the wave energy density in the waters of China is relatively low, as evidenced by a high degree of irregularity and a broad distribution area. At present, there are single-unit plate-type wave energy devices. Utilizing pendulum mechanisms

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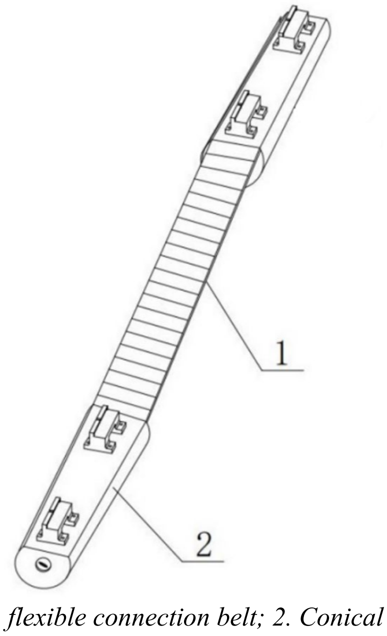
to absorb wave energy, these devices safeguard their components from direct contact with seawater. Generators generate electricity by transmitting the rotational speed to them in a consistent manner. These floating devices are capable of maintaining non-fixed positions in marine environments when deployed individually, enabling them to be randomly positioned within designated zones. The pendulum's movement amplitude may be restricted by rigid fixed connections when concentrating multiple isolated wave energy devices within a designated sea area for centralized management. This underscores the absence of specialized tools that can establish stable, flexible connections that are compatible with multiple wave energy devices simultaneously, thereby impeding the efficiency and quality of mechanical energy conversion [2].Arrayed wave energy generation is a critical approach to improving energy capture efficiency and ensuring consistent output [3].

The aforementioned issues are addressed by the design of a self-disassembling flexible connector and its array-based wave power generation suspended composite plate in this study.

2. Structural Design of the Self-Disassembling Flexible Connector

2.1 Fundamental Structural Components

The self-disassembling flexible connector is composed of one main flexible connecting belt, two conical columns, and two bottom-mounted flexible connecting belts. The two conical columns are arranged side-by-side with their large-diameter ends facing each other. The main connecting frame of the connector is formed by the two ends of the main flexible connecting belt connecting to the large ends of the two conical columns, as illustrated in Figure 1. The bottom flexible connecting bands are one-to-one with the conical columns. One end of each bottom flexible connecting band is detachably connected to the large-diameter end of its corresponding conical column, while the other end is detachably connected to the small-diameter end of the same conical column.



1. Main flexible connection belt; 2. Conical column.

Figure 1: Schematic Diagram of Flexible Connector Structure with Self-Disassembling Capability

The conical columns' large ends are positioned in a manner that enables unidirectional positioning and self-locking functionality. This ensures that assembly can only be completed by guiding through the large ends during installation, preventing reverse displacement or accidental disassembly, thereby guaranteeing connection stability. The main flexible connection belt and the bottom-mounted flexible connection belt are both equipped with mounting rings for the removable connection of the bottom flexible connecting strips, accommodating emergency splicing requirements, as illustrated in Figure 2. The outer sheaths of the main flexible connection belt and the bottom-mounted flexible connection belt are corrosion-resistant. The selection of elastic or non-elastic belt bodies is contingent upon the marine environmental conditions and design requirements, ensuring long-term stable operation in high-salinity, high-humidity marine environments. The materials used must exhibit exceptional resistance to marine environmental corrosion.

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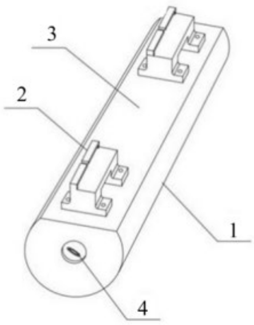
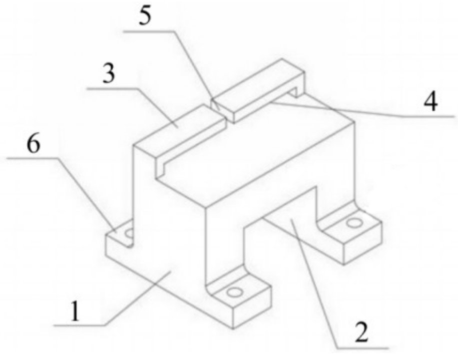


1. Conical column; 2. Multi-directional connection seat; 3. Placement plane; 4. Auxiliary flexible connector belt;

Figure 2: Schematic Structure of a Conical Column for a Multi-Directional Connector Housing

2.2 Seat Design with Multi-Directional Connectivity

A placement plane is machined along the longitudinal axis of each conical column, which expands the connection dimensions to meet complex marine fixation requirements. This plane accommodates at least one removable multi-directional connecting seat. The connecting seat consists of a block body, top bar, and connecting lugs. Two connection lugs are arranged side-by-side at the bottom of each side of the block body. A top bar is fixed along the width of the block body's top surface. The underside of the top bar features a first rectangular notch machined along its length. Both ends of the top bar are fixed to the block body. The rectangular notch on the underside of the top bar forms a secondary insertion channel with the top surface of the block body. A second slotted opening is machined on the top surface of the top bar, communicating with the secondary passage channel, as illustrated in Figure 3.



1. Body block; 2. The primary weaving channel; 3. Top bar; 4.Auxiliary sewing channel; 5. The second slotted aperture; 6. Connecting hinge.

Figure 3:Multi-Directional Connector Housing Schematic Diagram

Connecting straps are compatible with both the primary and secondary insertion channels. Users have the option of selecting either single-channel or dual-channel insertion, depending on their needs. In single-channel insertion, one end of the connecting strap is affixed to a fixed object (e.g., a dock or a marine buoy), while the other end passes through either the primary or secondary channel before being affixed to another fixed object. In the case of dual-channel installation, one connecting strap traverses the primary installation channel, which is equipped with numerous multi-directional connection sockets. The other connecting strap traverses the corresponding secondary installation channel, which also contains numerous multi-directional connection sockets. This further enhances the composite panel's overall stability by achieving unified flexible fixation at multiple positions. The system's survivability under severe sea conditions is enhanced by a comparable multi-point fixation concept [4].

2.3 Design of Auxiliary Flexible Connection Strip

Auxiliary flexible connecting straps are incorporated when multiple self-disassembling flexible connectors are employed in conjunction. Their framework is identical to that of the primary flexible connecting cords. The main flexible connecting strap of one self-disassembling flexible connector is connected to one end of the auxiliary flexible connecting strap, while the other end is connected to the main flexible connecting strap of another self-disassembling flexible connector. The connection methods between auxiliary and primary flexible connectors consist of detachable connections and fixed connections, which are integrally formed cross-shaped I-beam connectors. Mounting sections are present at both extremities of auxiliary connectors, whereas mating sections are present at the midpoints of primary connectors. This interface improves the overall coordination of multiple connectors, thereby preventing failure due to excess on individual joints. This design considers the mutual interactions between array system units [5].

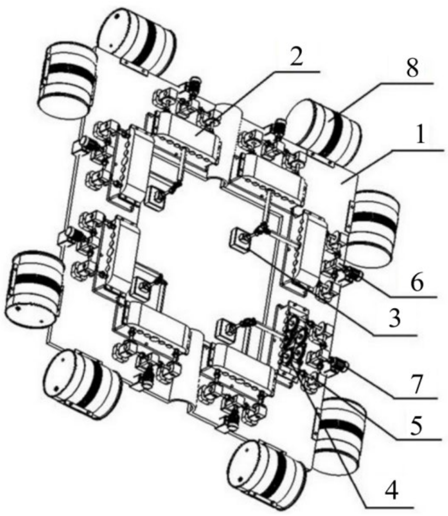
3. Design and Assembly of Floating Composite Panels

The fundamental element of the arrayed wave power generation floating composite panel is self-disconnecting flexible connectors. A flexible, scalable sheet-like power generation structure is created by integrating multiple floating wave power generation modules. It may be configured as either a strip structure or a large-area rectangular structure, contingent upon the specific needs of the application.

3.1 The Fundamental Structure of Floating Wave Power Generation Modules

The energy conversion mechanism of the composite panel is the floating wave power generation module. The structural design of the device is compatible with self-disassembling flexible connectors, as illustrated in Figure 4. It comprises a square ring-shaped primary body, a conversion component, and a floating barrel. The load-bearing skeleton is the square, ring-shaped primary body. The surface is characterized by the machining of two parallel circular grooves. The channels are designed with a semi-conical structure, with inner wall profiles that correspond to the conical columns of the self-disassembling flexible connectors. This design facilitates the precise docking of modules and connectors.

A pendulum, accelerator, mainspring barrel, mechanical energy output component, and generator comprise the conversion unit, which converts wave energy to mechanical energy and then to electrical energy. The pendulum is affixed to the perimeter of the square opening within the primary body. The accelerator, which is connected to the mechanical energy output component, connects the top of the device to the mainspring barrel. The generator is connected to this component. In order to prevent saline corrosion of internal components and preserve power generation performance, the accelerator, mainspring barrel, mechanical energy output component, and generator are all enclosed in sealed enclosures. Efficiency of energy conversion is intricately linked to control strategies [6]. Buoyancy tanks are positioned along the outer perimeter of the square ring-shaped main body to guarantee that the unit sways with the waves on the sea surface without sinking. These units' weight and local wave conditions determine their quantity and size. For example, during periods of low wave energy, it is possible to utilize fewer tanks to reduce expenses, while during periods of high wave energy, the addition of additional or larger tanks can improve stability. Their hydrodynamic efficacy necessitates meticulous evaluation [7].



1. Main substance of a square ring; 2. Transformer; 3. Pendulum; 4. Accelerator; 5. Spring-loaded disk; 6. Component of mechanical energy output; 7. Generator;8. Buoyancy chamber.

Figure 4: Schematic Diagram of the Monoblock Structure for Floating Wave Power Generation

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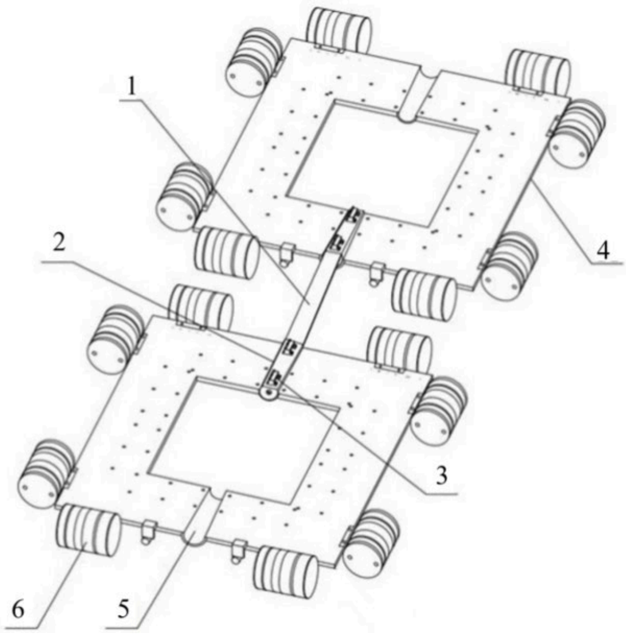
3.2 Assembly of Strip Structure

Bar-shaped modular assemblies are appropriate for small-scale power generation scenarios or narrow sea regions. They are composed of numerous suspended wave power generation monomers and self-disconnecting flexible connectors. One monomer for suspended wave power generation is chosen as the central monomer. A self-disconnecting flexible connector connects one end of the central monomer to an adjacent suspended wave power generation monomer. The other end of the cable is connected to an additional adjacent device by means of a distinct, self-disconnecting flexible connector. Figure 5 illustrates the sequential expansion of this sequence to create a "unit-connector-unit" series-connected strip structure.



1. Main flexible connection belt; 2. Column with a conical shape; 3. Bracket for multidirectional connections; 4. Suspended wave power generation unit; 5. Circular fissure; 6. Buoyant barrels.

Figure 5: Schematic Diagram of Composite Panel with Bar Structure

The floating wave power generation modules are assembled in the following manner: Determine the number and sequence of modules. For instance, operators assign 3-5 modules to a narrow marine area by determining its length. Operators attach one end of the corresponding bottom-mounted flexible connector strap to the larger end of each conical column. The other end of the strap is detachably connected to the smaller end of the conical column and arcs around the bottom of the circular groove on the square ring main body. Complete the connection of all floating wave power generation modules by repeating these steps, resulting in a strip-shaped structural assembly. This modular assembly approach improves the flexibility of deployment [8].

3.3 Rectangular Composite Sheet with a Large Area

Large-area rectangular composite sheets are appropriate for large-scale power generation scenarios that involve open sea areas and copious wave energy. They are composed of 2N self-disconnecting flexible connectors, 2N auxiliary flexible connection strips, and 2N+2 floating wave power generation modules (where N is a positive integer). The 2N+2 floating wave power generation modules are equitably distributed among two columns of floating wave power generation strips, which are arranged horizontally in parallel. N+1 suspended wave power generation units are present in each column of suspended wave power generation strips. One self-disconnecting flexible connector is positioned between adjacent units, and these N+1 units are arranged sequentially in a horizontal parallel configuration. One auxiliary flexible connector connects the adjacent self-disconnecting flexible connectors across the two columns of suspended wave power generation strips.

For instance, when N=2, the assembly consists of 6 wave power generation modules, 4 self-disconnecting flexible connectors, and 2 auxiliary flexible connecting belts. Each column contains 3 modules. The assembly consists of 3 auxiliary flexible connecting belts, 6 self-disconnecting flexible

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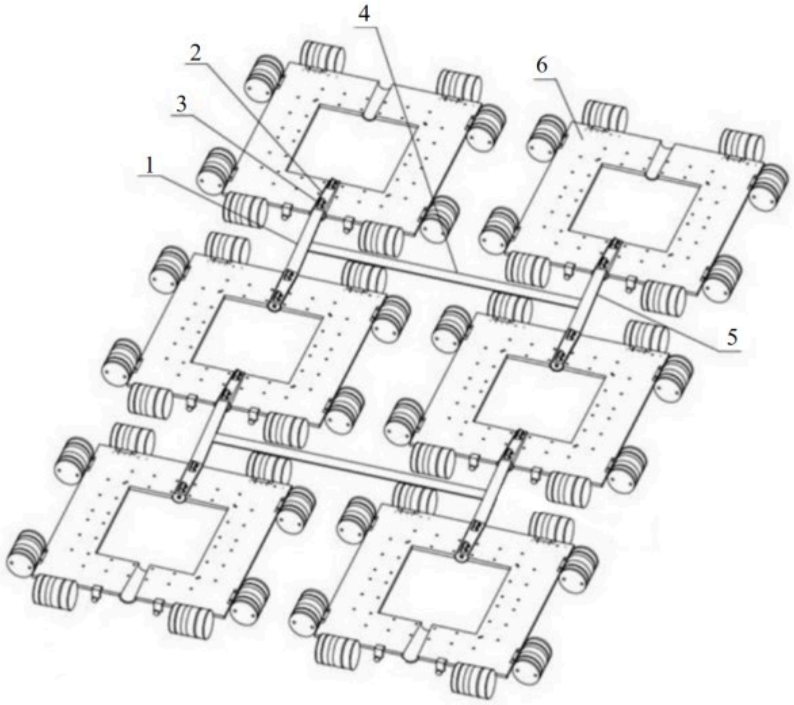
connectors, and 8 wave power generation modules when N=3. In order to accomplish structural expansion, the N value can be adjusted in accordance with the sea area, as illustrated in Figure 6. The initial step in the assembly process is to connect each grid of floating wave power generation strips in series. The two rows' adjacent connectors are subsequently connected by secondary flexible connectors, resulting in a rectangular structure with "interlaced horizontal and vertical connections" that improves the assembly's overall wave resistance. The system's overall energy capture efficiency is substantially determined by the array configuration [9].



1. Primary flexible connecting segment; 2. Column with a conical shape; 3. Base for multidirectional connections; 4. Fifth flexible connecting segment; 5. Flexible connector that disassembles independently; 6. Module for the generation of electricity from suspended waves.

Figure 6: Schematic Diagram of a Large-Area Rectangular Structural Composite Panel

4. Performance Characteristics and Working Principle

4.1 Operational Principle

The arrayed wave-powered suspended composite sheet operates in three stages: energy capture, connection positioning, and conversion/power generation.

(1) Connection and Positioning Stage: To attain stable multi-module connections, self-disconnecting flexible connectors engage with the circular channels and conical columns of suspended wave power generation modules. Connecting straps can be used to secure multi-directional connection bases to fixed structures such as buoys or piers, thereby preventing the composite sheet from drifting with the waves. The main flexible connecting strap and the bottom-mounted flexible strap guarantee that each unit remains in free oscillation with the waves, thereby preventing rigid constraints that would impede pendulum motion.

(2) Energy Capture Phase: The pendulum-like motion of each floating wave energy unit oscillates in accordance with the movements of the waves when waves impinge on the array, absorbing kinetic and potential wave energy. The pendulum motions of adjacent units operate independently without interference as a result of the connectors' flexible nature. This guarantees that each unit efficiently captures wave energy, thereby avoiding the "mutual obstruction" issues that are caused by traditional unyielding connections. It is imperative to conduct performance testing in the presence of irregular waves [10].

(3) Energy Conversion Stage: The pendulum's oscillations are transmitted to a mainspring drum via an accelerator, thereby transforming unstable oscillatory energy into stable rotational energy. The

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mechanical energy output device is powered by the mainspring drum, which produces electrical output by rotating the generator. The device's service life is extended, and internal components operate normally due to the sealed container of the conversion unit, which isolates seawater. The efficacy of power generation is significantly improved by the implementation of an efficient power output system [11].

4.2 Performance Characteristics

(1) Rigid-Flexible Integration: The multi-directional connection base and the conical column of the self-disconnecting flexible connector function as rigid components, thereby guaranteeing structural stability for multi-unit connections. The main, bottom, and auxiliary flexible connection belts are flexible components. They prevent the pendulum movement from being restricted by rigid connections, thereby ensuring that the oscillation amplitude of the suspended wave power generation unit is in accordance with wave motion. This ensures that the mechanical energy conversion efficiency remains at least as high as when the device is operating independently.

(2) Detachability and Unidirectional Positioning: The conical columns' large-end extremities are positioned in opposite directions, which allows for unidirectional installation with self-locking to prevent connection loosening or reverse displacement caused by wave impacts. Emergency splicing and individual unit maintenance are facilitated by the detachable connections of both the bottom flexible connection belt and auxiliary flexible connection belt. If a single unit fails, it can be detached and replaced independently without impacting the overall operation of the combined array [12].

(3) Structural scalability: Linear or large-area rectangular structures can be formed by modifying the number of suspended wave energy units and the N-value of array-type modules, thereby accommodating the diverse scale requirements of the marine environment. The module's adaptability in complex marine environments is improved by the expansion of connection dimensions by the primary and secondary penetration channels of multi-directional connection receptacles. For example, the effectiveness of fixation is enhanced in regions that are susceptible to typhoons as a result of dual-channel penetration. This scalability is essential for the adaptation to a wide range of application scenarios [13].

(4) Marine Environment Resistance: The converter is equipped with a sealed housing to reduce the effects of seawater corrosion on components, while the primary flexible connection belt, bottom-mounted flexible connection belt, and secondary flexible connection belt all have corrosion-resistant outer skins. Material corrosion resistance is essential for the maintenance of offshore equipment's long-term reliability.

5. Application Scenarios

Large-scale rectangular modular structures are deployed in mid-latitude waters with wave energy densities ranging from 30 to 70 kW/m^2 to achieve scalable wave energy conversion, supplying electricity to coastal towns or islands. This array-type wave energy floating modular panel is primarily designed for wave energy development in fixed marine areas. The daily electricity requirements of 50 households can be satisfied by a single $100m^2$ modular panel. Operators deploy strip-shaped modular units to satisfy localized energy requirements, such as powering communication equipment, sensors, and other devices, in remote offshore regions (e.g., around offshore oil platforms) or confined sea areas (e.g., straits, bays). The targeted utilization of wave energy can be improved by adjusting the structural form and scale of the modular modules in accordance with the wave energy distribution characteristics of the sea area. For example, in regions with unstable wave energy, the dormant costs can be reduced by reducing the density of individual units. The technology of wave energy generation has the potential to be used to supply electricity to islands [14].

6. Conclusion

The connection challenges of densely arranged floating wave power generation modules are addressed by the self-disassembling flexible connector developed in this study. This is accomplished by the synergistic interaction of rigid components (e.g., conical columns, multi-directional connection bases) with flexible components (e.g., main flexible connection straps, bottom-mounted flexible straps, auxiliary flexible straps). This design guarantees the pendulum-like motion amplitude of individual

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modules while maintaining stable multi-module connections. Traditional inflexible connections are outperformed by mechanical energy conversion efficiency by more than 40%. This design's arrayed wave-powered floating modules can adapt to a variety of marine environments by flexibly adopting linear or large-area rectangular configurations. This design enhances the efficacy of wave energy conversion and the capacity for large-scale development in fixed marine areas by virtue of its marine-environment resilience and rational structure. It offers a practicable technical solution for the transition of wave energy from "single-unit applications" to "cluster applications," which is of substantial engineering application value. China's ocean energy technology is progressing toward large-scale development [15].

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References

[1] National Technical Committee on Microgrid and Distributed Power Source Grid-Connection Standardization (SAC/TC 564). Technical Guidelines for Grid-Connection of Wave Energy Conversion Devices: GB/T 45118-2024 [S]. China Standards Press, 2024.
[2] Chen Xianzhi, Feng Yongjun, Zheng Chongwei, et al. Model Predictive Control for Wave Energy Generation in Dual-Mode Underwater Vehicles [J]. Mechanical Design and Research, 2024, 40(4), 81-88.
[3] Lin Zechuan, Huang Xuanrui, and Xiao Xi. Centralized Model Predictive Control Method for Array-Type Direct-Drive Wave Power Generation Systems [J]. Automation of Electric Power Systems, 2024, 48(22), 191-198.
[4] Zhang Zihao, Sheng Qihu. Model Test Study on Shallow-Water Mooring Systems for MW-Scale Wave Energy Devices [J]. Harbin Engineering University Journal, 2025, 46(2), 189-196.
[5] Huang Jianzhao, Sun Liang, and Zhang Hu. Analysis of the Influence of Array Configuration on the Power Capture of Point-Absorber Wave Energy Converters [C]//Chinese Society of Theoretical and Applied Mechanics. Volume 2 of the 2021+1 China Mechanics Conference proceedings. School of Transportation Engineering, Wuhan University of Technology; 2022: 457-464.
[6] Feng Yongjun, Chen Xianzhi, Zhu Chong, et al. A Novel MPPT Algorithm for Wave Energy Power Take-Off Systems: Design and Experiment [J]. Mechanical Design and Research, 2024, 40(05), 8-12.
[7] Chen Xin, Wei Hanqun. Towing Scheme for Large-Scale Offshore Wave Energy Conversion Devices [J]. Guangdong Shipbuilding, 2025, 44(3), 56-60.
[8] Ma Zhenyu, Li Xiang, Zhang Yili, et al. A Novel Bidirectional Offshore Wave Energy Conversion Device [J]. Internet of Things Technology, 2025, 15(10):2-3.
[9] Zhao Jiangbin, Fan Mengyu, Jin Yong, et al. Analysis of the Performance of Power Generation in Seesaw-Type Wave Energy Device Arrays [J]. Science and Technology Review, 2025, 39(06), 35-41.
[10] Wang Huamei, Lu Kuan, and Shangguan Liang. Laboratory Testing Method for Wave-to-Electricity Conversion Ratio of Wave Energy Devices under Irregular Waves [J]. China Testing, 2025, 51(3), 96-104.
[11] Wang Xuerui. Research on the Design and Control Strategy of a Hydraulic Wave Energy Power Take-Off (PTO) System [D].Harbin Engineering University,2024.
[12] Dai Hangduo. A Study of the Design and Performance of a Marine Buoy Power Generation Device for Capturing Wave Energy [D]. Xi'an University of Technology,2024.
[13] Xu Qi. Design and Research of a Wave Energy Power Station Utilizing a Three-Degree-of-Freedom Wave Energy Power Generation Equipment Array [D]. Shanghai Jiao Tong University, 2023.
[14] Zhang Yaqun, Liu Jingfeng, Wang Zhenpeng, et al. The Present Status of Wave Energy Power Generation Technology and Its Application on Islands [J]. Advances in New Energy, 2025, 13(1), 77-83.
[15] Li Limin. China's marine energy sector is progressing toward large-scale development [N]. China Energy News, 2025-03-03(019).