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Exploration of the progression and innovation in harnessing wave energy resources and the implementation of cutting-edge wave power generation apparatuses along China's coastal regions

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Abstract. In the current international environment, energy is in short supply and environmental pollution is increasingly serious. The development of marine resources is favored by many countries and regions because of its environmental protection and renewable nature. Among them, wave energy is an extremely important kind of marine energy, which is now receiving the world's attention step by step and has achieved some research results. This paper analyzes the current enrichment and distribution of wave energy resources in China's sea areas, and studies the future development trend of wave energy in China on this basis. Based on the above experimental data analysis, this paper introduces the wave energy power generation devices that have completed sea trials in China in recent years, and finally looks forward to the future development direction and trend of wave energy, and points out the current shortcomings and improvement methods of wave energy, which has a certain degree of practical application value.

Keywords: wave energy, resource distribution, development trend, power generation device, overview.

1. Introduction

In the context of rapid global economic development and continuous social progress, energy shortage, environmental pollution, rapid population growth and other issues have increasingly become key factors restricting the development of national comprehensive strength and the improvement of human living standards [1]. The reserves of traditional fossil fuels such as coal and oil are limited and seriously pollute the environment. To alleviate the tension between supply and demand of traditional energy and cope with the energy crisis and severe environmental problems, researchers have been committed to finding renewable and clean energy that can replace traditional energy [2]. As a new renewable and clean energy, wave energy has large reserves and wide distribution, and has been increasingly valued by researchers in China, so the research on wave energy has gradually deepened.

The ocean, which covers 70.8% of the Earth's surface, contains various types of energy that are stored in significant amounts. These predominant energy forms encompass wave energy, tidal power, oceanic current potential, thermal gradient energy, salinity gradient power, and beyond, minimizing repetition for a refined expression.[3]. Wave energy is essentially the kinetic and potential energy generated by the ocean as a result of absorbing wind energy. Consequently, wave energy boasts merits like elevated

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energy density and extensive dispersion. Throughout high-demand winter months, a copious supply of wave energy remains accessible for exploitation, reducing redundancy for an advanced expression [4]. China's wealth in oceanic wave energy resources is vast, and the robust development and harnessing of these assets hold substantial strategic importance in executing the nation's sustainable development agenda and mitigating energy challenges arising from the scarcity of traditional energy sources.[5]. Therefore, in this context, effective research and utilization of wave energy resources possess high scientific research value and economic value for China.

2. Research status of wave energy in China

Wave energy utilization technology has undergone various phases, including apparatus innovation, laboratory experimentation and investigation, as well as real-world maritime application demonstrations. Fundamental design and construction challenges have been largely addressed. The subsequent objective involves constructing wave energy equipment capable of attaining commercial-scale utilization, diminishing expenses, and enhancing efficiency and dependability. [6]. In today's world, wave energy is gradually being paid attention to. Compared with other countries, China's research on wave energy technology started late, and there is still a certain gap in technology compared with the UK and other technologically advanced countries. However, in recent years, China's emphasis on renewable energy has increased, and the development of wave energy power generation technology has also made considerable progress.

2.1. Classification of wave energy devices

Up to now, there are a variety of wave energy power generation devices around the world, with more than 1500 patents related to wave energy. At present, there are three mainstream wave energy power generation devices in the world. One is the oscillating water column type, which uses the air flow of the waves moving up and down on the sea to drive the turbine to rotate; The second category encompasses overtopping devices that employ the mechanical energy derived from the motion of ocean wave energy apparatuses (linear reciprocation, swaying, and rotation) to transform into electrical power. The third classification involves oscillating float systems that harness wave energy to channel water into elevated storage tanks, generating a hydraulic head, which subsequently drives turbines for electricity production. Oscillating water column devices can be subdivided into stationary and floating variants. Oscillating float systems can be further classified into point absorber, hybrid, and pendulum types (nodding duck and raft configurations).

2.2. Examples of wave energy installation projects in China

The promulgation of the Renewable Energy Law in 2005 is a milestone in the history of renewable energy development in China. With the stimulation of relevant policies, the development of wave energy devices in China has also entered a stage of rapid development. At present, most of the devices that have completed the sea trial are oscillating devices.

In 2014, the rack and pinion oscillating float-type wave energy power generation device developed by China Ocean University was tested at sea in the Shazikou sea area of Qingdao. The device is composed of float, damping plate-type latent body and counterweight. The mechanical energy transfer mechanism, power conversion and storage components are sealed inside the float. The installed capacity is 1 kW, which can realize the one-way output of electric energy under the double-stroke motion of the float.

The National Marine Technology Center mainly researches and develops the pendulous wave energy power generation device. In 2012, with the support of the national science and technology plan, a 100 kW bottom hinge pendulum device was developed and tested in the sea area of Daguan Island, Jimo, Qingdao, Shandong Province.

In 1990, China's navigation lightship "Zhongshui No. 1", which is equipped with a backward-bending oscillating water column wave energy conversion system, successfully completed a one-year sea test. During the "Eighth Five-Year Plan" period, the model performance test of the wave energy

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power generation ship developed by China was carried out. The power generation principle of the "Zhong Shui No.1" lightship and the rear bend wave power generation ship is like that of the "Hai ming" and "Ju jing". In 2012, China's "Eagle 1" oscillating float-type semi-submersible ship conducted a sea trial in the Wanchengshan sea area.

On April 17, 2013, the floating wave power generation device - 100kW canard wave power device, developed by the Chinese Academy of Sciences Guangzhou Energy Research Institute, was transported to Dawanshan Island, Wanshan District, Zhuhai City through the self-developed floating dock. It was successfully launched in the designated sea area. At present, it has been running smoothly and generating power successfully [7].

In recent years, China has also made many achievements in the field of wave power generation. For example, the "10 kW combined oscillating float wave energy power generation device" independently developed by China was put into use in January 2014 [8].

3. Analysis of China's coastal wave energy resources

This paper also analyzes the wave energy resources along the coast of China. The amount of wave energy development is huge. Once it is impossible to accurately judge the development of the wave energy resource-rich areas, the losses will be huge. Therefore, when developing the wave energy power generation industry in China, it is necessary to strictly demonstrate the feasibility of project site selection and reasonably select the wave energy conversion device in close combination with the actual distribution law of wave energy in the domestic sea area, Avoid the huge waste caused by blind investment (preliminary study on wave energy distribution along the coast of Chinese Mainland), so this paper has certain engineering construction guidance value.

3.1. Characteristics of wave energy resources in Chinese Mainland

The potential amount of wave energy resources in China is estimated to be around 770 × 104 kW, with Guangdong Province having the richest resources, followed by Fujian Province, Zhejiang Province, and Hainan Province.

In terms of tidal current energy resources, Zhejiang Province has the largest distribution along the coast of China, with 37 waterways and a theoretical average power of 709 × 104 kW, accounting for more than half of the national total. The second largest distribution is in Taiwan, Fujian, Shandong, and Liaoning provinces, which have more coastal areas and a total theoretical power of between 113 and 228 × 104 kW, adding up to 587 × 104 kW, accounting for 41.9% of the national total. Other provinces and regions have less coastal areas, with Guangxi having the least at only 23 × 103 kW.

The most abundant tidal current energy resources are distributed along the East China Sea coastline, featuring 95 channels and a theoretical average power of 1096 × 10^4 kW, constituting 78.6% of the national aggregate. The Yellow Sea coastline, primarily along the northern region, contains 12 channels and a cumulative theoretical power of 230 × 10^4 kW, representing 16.5% of the national sum. The South China Sea coastline exhibits the sparsest distribution, with a mere 23 channels and 68 × 10^4 kW, accounting for 4.9% of the nationwide total [9].

3.2. Characteristics of wave energy resources in Taiwan, China

The coastal area on the east side of Taiwan Island is the most concentrated sea area of wave energy in China, and the annual average wave energy power value is about 9 kW/m; The sea area on the east side of Hainan Island takes the second place, and the annual average wave energy power value is about 7 kW/m. In terms of the size of energy current density, the frequency of available wave heights, and the reserves of wave energy resources, the waters around Taiwan contain relatively rich wave energy resources. The relatively rich areas are distributed in the waters near Keelung, Hualien, Chenggong Dawu and Penghu, and the relatively poor areas are distributed in the waters near Kaohsiung.

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4. Problems in current utilization of wave energy

(1) From an energy conversion efficiency perspective, wave energy power generation technology is still in its early stages. Compared to mature power generation methods like thermal and wind power generation, wave energy power generation technology has significant room for improvement. Improving its technical framework is crucial to keep pace with national strategic development.

(2) The development of wave energy is uncertain due to the environmental conditions of the wave capture area. The sea surface is often subjected to unpredictable adverse environments, and ocean waves are constantly changing, resulting in scattered and low concentrated wave energy. Thus, the overall energy conversion efficiency of wave energy power generation devices is low. This technological limitation makes it difficult to ensure the long-term efficiency of wave energy power generation devices.

(3) There are practical issues facing the development of wave energy at the current stage, particularly in terms of economics. According to relevant calculations, the cost of generating conventional thermal power is only one-tenth that of ocean wave power generation. This makes it a less attractive option for enterprises seeking economic benefits. It is therefore necessary to reduce costs as much as possible and strive to achieve the largest amount of power generation with the simplest devices.

5. Thinking and conclusion

China, a nation richly endowed with wave energy reserves, presently incorporates a multitude of wave-powered electricity generation contrivances in its engineering endeavors. The preeminent energy-harvesting apparatuses can be delineated into oscillating water column, overtopping, and oscillating float archetypes. At this juncture, wave energy technology has not yet permeated mainstream utilization, as the evolution of diverse methodologies transpires along divergent developmental vectors.The space for development is still huge, but the development trend is to continue to improve the efficiency and utilization of power generation, The development of marine energy capture rate is to form low-cost mature technology. Finally, through large-scale production and application, the cost of power generation can be significantly reduced. The research objectives of various wave energy power generation devices are mainly to optimize the overall power generation performance of the device (including power generation stability and efficiency), improve the maintainability and sustainable working ability of the device, and enhance the viability of the device under adverse sea conditions.

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