Marine Power Generation Methods and Future Developments

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Abstract. With the continuous advancement of science and technology, ocean energy continues to develop because of its renewable, clean and stable advantages. This paper mainly studies the issue of ocean energy power generation, focusing on tidal energy power generation, wave energy power generation and ocean current power generation. The practical application of tidal energy power generation, and the negative and positive impacts of clean energy such as tidal energy on the marine environment after application, various methods and advantages and disadvantages of ocean current/ocean current power generation are described, and the explanation of many instruments in these power generation methods. For instance, the equipment used in tidal energy, wave energy and ocean current power generation are oscillating water column wave energy converter, mechanical wave energy generation, the diffuser-augmented floating hydro turbine, Darrieus deep-sea vertical axis turbine and so on. At last, from the actual cases of China's use of clean energy such as tidal energy and wave energy to generate electricity, we analyzed the future development trend of ocean energy and concluded that ocean energy will be vigorously developed in the future to replace some fossil energy.

Keywords: Tidal power generation; Wave power generation; Ocean current power generation.

1. Introduction

Ocean energy, which includes tidal energy, mechanical energy generated by waves, ocean current energy, osmotic energy, etc., is defined as renewable energy that is stored in the ocean.

How to effectively use marine energy is the orientation of energy research in the world today. Especially under the circumstances that the earth's mineral energy reserves continue to decrease, the environment continues to deteriorate, and energy is linked to national security, figuring out how to effectively use marine energy is becoming increasingly important. Turning ocean energy into electricity at a low cost will open up a new way to alleviate energy shortages and environmental problems. The development of marine energy power production is often trailing behind because the operating environment for marine energy power generation systems is typically poorer, facing more risks and problems. Overall, the use of ocean energy for power generation has great latent capacity, and with the continuous development of new technologies, the prospects for human development of ocean energy are increasingly broad. With the support of the macro-policies of countries around the world, the promotion of the external environment, and the support of funds, after years of scientific research, testing, development, and utilization, marine energy power generation has achieved a certain level of technology and production foundation, but at present, there are still problems such as large investment, small scale, low profitability, and lack of market competitiveness.

In this study, wave energy, tidal energy, and current energy in ocean energy will be selected for research. Through the reading of a large number of relevant documents and materials, the background and history of the application of these three kinds of marine energy, the significance of their development, and specific application methods are studied in detail. Therefore, the advantages and disadvantages, current situation, and application prospects of various power generation methods are summarized comprehensively and objectively.

2. Wave Power Generation

Wave energy collection, energy transfer, and the transformation of mechanical energy into electrical energy are the three main processes of wave energy conversion. In comparison to conventional power generation, wave power generation has more unique requirements and calls for a constant input of energy. It must create floating structures at sea and find a solution to the transmission of power underwater issue. Along the coast, special hydraulic constructions are required. The various wave energy harvesting technologies used nowadays include shaking duck, rectification, oscillating water column, and more.

2.1. Oscillating Water Column Wave Energy Converter

The oscillating water column's wave energy conversion device (shown in Fig. 1) is composed of three parts: a wave absorption device, an energy conversion device, and an energy output device [1]. Its basic operating concept is straightforward. The wave energy must first be absorbed using a wave absorption device, then converted using a wave energy conversion device, and then sent to the energy application end using an output device to successfully convert wave energy into a useable form. The first step in the energy conversion process is the wave absorption, which comprises of a float and a gas chamber that detects and absorbs the wave energy. Second, the energy conversion mechanism oscillates the air chamber and air supply pipe to transform wave energy into wind energy using the lever principle. The energy output device then carries out the mechanical energy conversion of wind energy using the generator and the air turbine system. The generator's output terminal produces electric energy when in use.

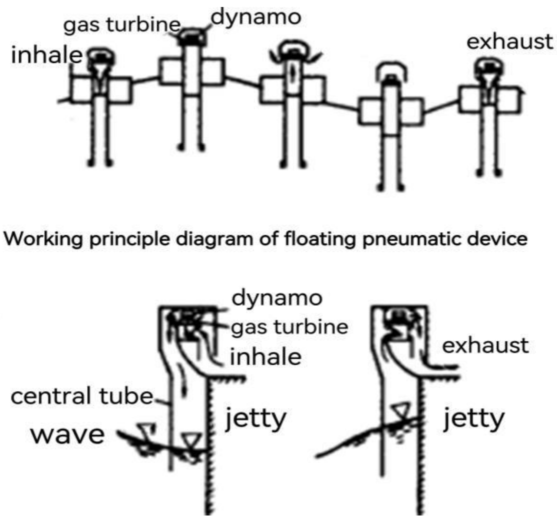

Fig 1. Schematic of oscillating water column wave energy converter (OWC).

Wave energy devices come in three main categories. Oscillating body, ultra-top gadget, and oscillating water column (OWC). One of the most promising technologies is OWC. The key justifications are as follows: it can be easily made more affordable; its installation is very flexible; it can be done in offshore locations and breakwaters. An air chamber and an air column make up its very basic structure. Numerous studies have been conducted to enhance OWC system performance. It is discovered that the geometrical characteristics of the device, such as the bottom bevel, the chamber's bottom profile structure, its length, the front wall flow, and the power output damping (PTO), significantly affect the effectiveness of the capture. The air chamber's optimal shape design may increase its ability to gather energy. Studying the BBDB OWC units' dynamic performance, an ideal plan for raising annual power generation is put forth. A novel hybrid wave energy converter that combines OWC and super devices is proposed in [2]. It has been discovered that hybrid systems operate more effectively than separate components do. It has been discovered that hybrid systems perform better than separate components do. Both theoretically and experimentally, the hydrodynamic performance of a multi-oscillating water column is investigated. The experimental findings of the fixed offshore OWC model in irregular waves were reported and the effect of wave spectral form on efficiency was investigated in [3]. The performance of the OWC system overall under the irregular fluctuation scenario was examined in [4]. They discovered that cabin performance is greatly impacted by turbine speed. Self-rectifying air turbines were compared by [5]. Different turbines' performances were examined, and it was determined whether they were suitable for various OWC applications in varied operating environments. A new OWC device, known as the U-oscillating water column (U-OWC) wave energy converter, was recently proposed in [6]. The water column in the U-OWC system is connected to the open offshore field by a further vertical pipe that is erected in front of the skirt wall. The U-OWC operates like a typical OWC. An air turbine attached to a generator uses the reciprocating air flow produced by the water column's oscillating motion created when an incident wave enters a space to drive the generator. It has been discovered that the U-OWC vertical air duct may extend the resonance period without phase control under specific circumstances, hence increasing the energy conversion efficiency of the air chamber. Additionally, the stability and safety of the U-OWC unit are improved, and the fluctuation load of the entire structure is decreased. The U-OWC also has the benefit of reducing the quantity of sand and debris entering the chamber by blocking vertical pipes. Malara et al. [7] offered a linearized wave theory-based analytical explanation of U-OWC dynamics and a congruent depiction of the interaction between wave field and U-OWC.

2.2. Mechanical Wave Energy Generation

In order to run the generator and produce electricity, a transmission mechanism converts the wave energy from the reciprocating motion to the one-way rotation motion. a mechanical device with rack, pinion, and ratchet movements (shown in Fig. 2). The rack and the float rise and fall in tandem with the waves, pushing the left and right gears attached to it for reciprocating rotation. Each gear has a ratchet mechanism that connects it to the shaft. The rack rises, the left gear rotates its shaft in the opposite direction from the right gear, which idles. Drive the generator to rotate in a clockwise direction to produce power using the rear stage gear transmission. Most mechanical gadgets are bulky, unreliable, and useless.

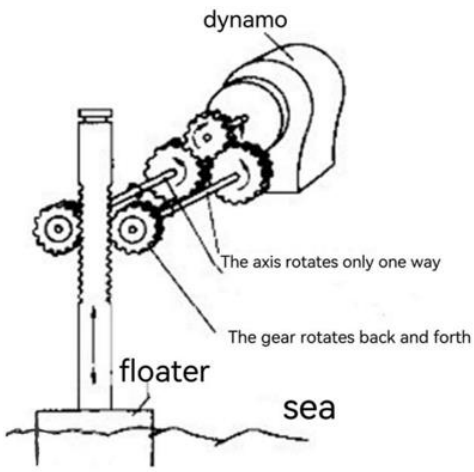

Fig 2. Schematic of mechanical wave energy generation.

2.3. Technical Achievements in China

A new development in China's ocean power generation technology occurred with the launch of the "Ying No. 1" floating wave power generation device in the Wanshan Islands of Zhuhai City, which is situated at the mouth of the Pearl River. With new energy taking center stage, marine power generating technology has caught people's interest thanks to its distinct benefits and advantageous location, and the world's main maritime nations generally place a high value on the exploitation and development of the ocean. A research team from the Guangzhou Institute of Energy Research, Chinese Academy of Sciences, produced the Ying-type floating wave energy producing gadget after 1.5 years as a sort of ocean wave energy utilization technology. The research team created a total of

5 sets of device models by continuously optimizing and enhancing the device model. Numerous tests were conducted in the two-dimensional and three-dimensional flumes, respectively, before the combination of a lightweight wave energy absorber and a semi-submersible vessel was chosen as the final design concept for the real sea state device. The test findings demonstrate that the new apparatus satisfies the requirement for quick, risk-free, and inexpensive research and development of an ocean wave energy generation device and establishes a strong basis for the large-scale development and use of ocean wave energy.

2.4. Summary

The cost of large-scale wave energy generation is still difficult to compete with that of conventional energy generation, but low-power wave energy generation for special purposes has been popularized and applied in navigation light buoys, lamp piles, lighthouses and so on. In remote islands, small wave power generation has become competitive with diesel generators. In the future, new devices should be further developed to improve the efficiency of wave energy conversion. To improve the density of wave energy, reduce the size of the device and reduce the cost; In order to improve the economic efficiency of wave power generation, we will study the use of factory ships to generate power locally and produce energy-intensive products, such as hydrogen and ammonia production by electrolysis of seawater, aluminum production by electrolysis and uranium extraction, in sea areas far away from the mainland and rich in wave energy. It is expected that with the depletion of fossil energy resources and the progress of technology, wave power generation will gradually occupy a certain position in countries rich in wave energy.

3. Tidal Power Generation

Tides are the ups and downs of the sea surface in the vertical direction. Marine tidal stream is reflected as a reliable renewable power generation source owing to its predictability present in tidal current. Globally, tidal energy production for the coastal areas, is estimated around 1 TW*h per annum [8]. Tidal energy is the energy possessed by the periodic fluctuation of seawater, and it is a renewable and clean energy. Therefore, the technology of utilizing tidal energy to generate electricity continues to develop.

3.1. Three Methods of Tidal Power Generation

The methods of tidal power generation include double-storage (shown in Fig. 3), single-storage one-way (shown in Fig. 4), single-storage two-way (shown in Fig. 5), power generation combined with pumped storage, etc.

A single-storage and one-way tidal power station refers to a single-storage and one-way operation power station that uses high tide to store water and ebb tide to generate electricity.

The single-reservoir two-way type refers to the construction of a reservoir, the installation of generating units that can generate electricity at high tide and low tide, or meet the two-way power generation in terms of hydraulic layout. In a tidal cycle, there are six operating conditions of the power station: waiting - high tide power generation - water injection - waiting - low tide power generation - water release. Generally, low tide power generation is the main source.

All-time tidal power generation can be achieved by creating two reservoirs. It makes use of two nearby reservoirs so that during high tide, the first reservoir absorbs water and during low tide, the second reservoir discharges water. The former is hence referred to as a high water level reservoir, whereas the latter is referred to as a low water level reservoir. To achieve all-time power generation, the generator set is installed in the dam between the two reservoirs, where there is always a difference in water level.

In the power station reservoir, where the water level is close to the tide level and the water head is small, power generation combined with pumped storage is used. Pumped storage uses power from the grid. To enhance the effective water head during power generation and increase power generation, sea water is pumped into the reservoir when the tide is high, while reservoir water is pumped into the sea when the tide is low. The single-storage one-way type generates energy twice daily and at night, with an average daily power generation of 9 to 11 hours, according to the standard half-day cycle tide meter. Compared with the single-storage one-way type, the average power generation efficiency is lower than that of the single-storage one-way type, and the unit structure is more complicated due to the consideration of both positive and negative power generation. Research at home and abroad believes that the cost of double storage is expensive, and the single storage is better for low tide power generation. However, which method is the best should be selected according to the technical and economic indicators such as local tidal pattern, tidal range, terrain conditions, load requirements of the power system, composition of power generation equipment, building materials and construction conditions.

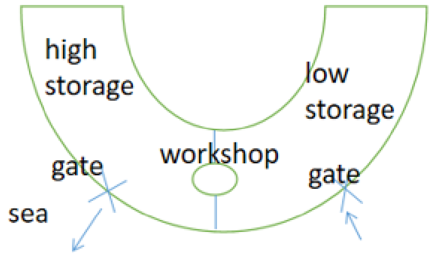

Fig 3. Dual-reservoir tidal power station.

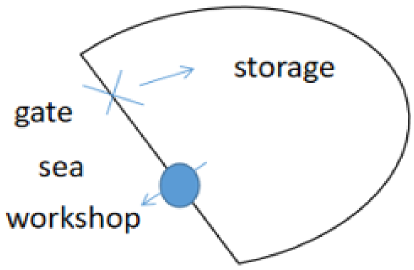

Fig 4. Single-storage one-way tidal power station.

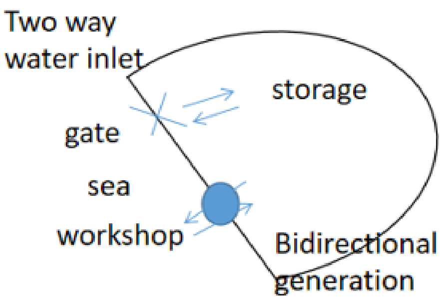

Fig 5. The single-reservoir two-way type station.

3.2. Advantages and Disadvantages

The advantages of single-storage and one-way tidal power generation are that the required technical level and construction cost are low, and the required power generation base covers a small area, so it can still be constructed in many countries with relatively underdeveloped technology to achieve the purpose of promoting tidal power generation. However, because this power generation method is to open the door when the tide is high and close when the tide is low, it is not possible to achieve all-weather power generation due to time constraints. At the same time, this also means that the utilization rate of tidal energy is very low, and power generation can only be driven after the ebb. In addition, this power generation method has high requirements on the geographical environment and requires a certain terrain drop, so the natural aspects of this method are relatively limited.

Single-storage and two-way power generation means that both high tide and high tide generate electricity, which is used in conjunction with pumping. Compared with the single-storage one-way power generation method, the two-way power generation can generate electricity at both high tide and low tide, so the single-storage two-way power generation has higher timeliness, but the single-storage two-way power generation still cannot generate electricity for the whole time period, because in order to Better power generation, both high tide and low tide have a period of downtime and standby, until the high tide or down to half the tidal range, but the time used for power generation is far more than the time and the standby time of pumping water. Although the single-storage two-way power generation method still has many limitations, under today's social background, the single-storage two-way power generation method is the most widely used in combination with technological level, construction cost, geographical environment, and many other factors. Tidal power generation method.

The dual-storage two-way power generation method can generate tidal energy all day long and all-weather. Because there are generator sets arranged between the two water storage, this power generation method cannot be limited by the time limit of the rising tide of the sea, and only use two The water level difference of the reservoir can generate electricity, but because the economic cost of this power generation method is too expensive, it is rarely used in the current global tidal power generation.

3.3. The Environmental Influence

Tidal change will have an effect on the bay's area in the marine environment, which will be destructive to the species there and cause a decrease in the amount of living space for them. And because the water in the TPP reservoir cannot be easily exchanged for seawater, the reservoir must be refilled with freshwater from the land [9].

The water temperature, salinity, and sediment concentration in the reservoir will fluctuate, and the stable environment will be damaged, if river water with a substantial run-off or sediment concentration flows into the reservoir. TPP construction will affect the marine and offshore land environments in the plant's vicinity as well as the conversion of water flow between the bay and the sea, which will ultimately have an effect on the emergence of an ecosystem in the sea area. The flow is less constant and the gulf water exchange in TPPs is less smooth, which will cause the sediment dynamics in the reservoir to change. This will lead to more sediment being deposited along the gulf coast, which will have an impact on the survival of the marine benthos [9].

From the above, it can be concluded that the construction of tidal energy power stations will have a negative impact on the marine environment and ecological balance, but tidal energy power generation can optimize the atmospheric environment. Due to the development of tidal energy, the use of fossil fuels can be greatly reduced, and the content of carbon dioxide in the atmosphere will be greatly reduced, conducive to China's goal of carbon neutrality in 2030. And the negative impact on the marine environment can be fully compensated by other measures, so generally speaking, the use of tidal energy for power generation is beneficial to the overall environment.

3.4. Summary

The single-cell two-way power generation method is the most widely used tidal power generation method at the current technological level. With the advancement of science and technology in the future, the cost of dual-cell bidirectional power generation will be continuously reduced, and then it will become the mainstream of tidal power generation. Since this article does not know the specific economic strength and geographical conditions of other regions, it only judges the prospects of tidal energy in China, and will conduct further research on global tidal energy in the future.

4. Ocean Current Power Generation

Ocean current refers to the regular, horizontal flow of seawater with a relatively constant speed in one direction. It is a large-scale movement from one sea area to another, horizontally or vertically. It is the primary form of movement in sea water, which contains enormous energy. Ocean currents follow a predictable path week after week in oceanic motion. Although this energy is usually diffuse, it will still concentrate in some places where the current is directed toward the surrounding area or through restrictive terrain such as islands and straits. There are many potential sites in the world that can be developed and utilized. In addition, ocean current resources are highly predictable, so their conversion into available energy has advantages over other renewable energy sources.

Ocean current power generation usually uses the impact of the ocean current to rotate the blades of the turbine to propel the generator to produce electricity. The general marine current power generation system using hydraulic turbines is composed of hydraulic turbines, transmission devices, control devices, etc. Unlike conventional turbines with reservoirs that rotate the blades through the water pressure difference, the hydraulic turbine in ocean current power generation directly converts energy of motion into mechanical energy that drives the generator to generate electricity. Therefore, the turbine for sea current power generation is a kind of turbine without pressure to reduce the head, and the output power of the generator hinges on the current's speed. Therefore, the vertical shaft turbine is more widely used than the horizontal shaft turbine. In addition to the hydraulic turbine, other structures such as underwater windmill, spiral turbine, cross-flow turbine, wreath, barge, umbrella, Coriolis, superconducting magnet, etc. are also available.

4.1. The Diffuser-augmented Floating Hydro Turbine

This is a brand-new hydraulic turbine design that is characterized by autonomy, self-regulation, low cost, and a long service life. The hydraulic turbine is composed of two pontoons arranged side by side (shown in Fig. 6). The internal shape of the pontoons can form an open channel with variable section, which helps to improve the flow velocity near the rotor. The advantage of a floating system in deep-water operation compared with a full flooding system is that it is easier to install and remove, so it is more flexible, and the daily maintenance is simpler, which greatly reduces the maintenance cost. Its moving components are smaller, which makes the design process easier and lowers the cost of manufacture. The advantage of introducing the guide device is that when the geometric design of the rotor is the same and the surrounding flow velocity is the same, it can produce a higher speed. The diversion device greatly reduces the cost of the transmission system, which helps to reduce the size of the machine, thereby reducing costs. Compared with the traditional turbine, the diffuser-augmented floating hydro turbine has lower cost, stronger reliability, and higher flexibility.

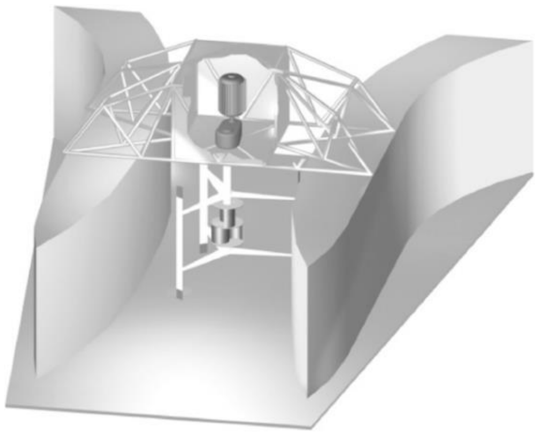

Fig 6. Structure of Diffuser Enhanced Floating Turbine [10].

4.2. Darrieus Deep-sea Vertical Axis Turbine

This is a hydraulic turbine designed for long-term power generation in the deep sea. Darrieus type vertical axis impeller is designed to be independent of the incoming flow direction, and airfoil optimization and spiral structure design are carried out to improve the efficiency, stability, and self-starting performance of the impeller. When working in the deep-sea environment, the equipment will face problems such as low water velocity and complex changes in the incoming direction. The traditional horizontal-axis power generation impeller has high requirements for the direction of seawater flow. The advantages of the vertical axis impeller design, which is not affected by the incoming direction, can solve this problem well. Fig. 7 shows the model design of the power generation impeller. When facing the incoming flow in any direction, the average lifting torque of the blade can always maintain the clockwise rotation of the impeller. The design of the spiral can make the stress on the impeller at each rotation angle higher. Fig. 8 shows the blade section. The vertical axis impeller uses the lifting torque generated by this blade type to drive the impeller so as to capture the kinetic energy of the horizontal 360-degree incoming current.

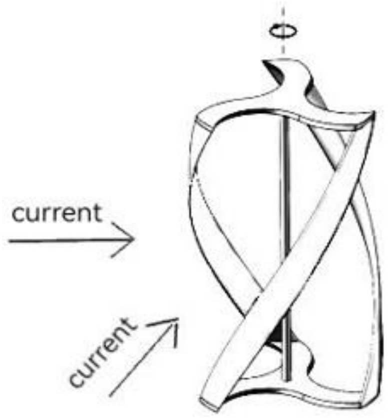

Fig 7. Structure of Darrieus vertical shaft impeller.

Fig 8. Cross section drawing.

4.3. Kite-type Current Generator

Underwater kites-type current generator is shown in Fig. 9. It consists of a turbine generator in the shape of a kite and a rope chain containing cables. Underwater kites are tied to the sea floor and generate continuous energy through ocean currents. Take the underwater kite power generation turbine recently developed by Minesto Company as an example. Each turbine can generate up to 1.2 MW of electricity. The underwater kite has a wingspan of about 12 meters. It will be placed about 20 meters below the water's surface to prevent conflicts with ocean navigation. The underwater kite is equipped with a turbine generator about 1 meter long, which is fastened to the seabed by means of rope chains. When the speed of the current reaches 1.6 meters per second, the energy generated by the current is enough to make the underwater kite rotate. Its rope chain is also used as a cable, which not only plays a role in fixing the underwater kite but also makes it move at a high speed in the water with a figure-eight track to generate more energy. As the underwater kite is tied to the bottom of the sea, it can move at a faster speed (about 10 times the speed of seawater flowing at its operating position). Because underwater kites are controllable, they can avoid collisions with other moving objects by actively avoiding them, which not only avoids possible damage and wear to themselves but also reduces their potential risks to marine organisms.

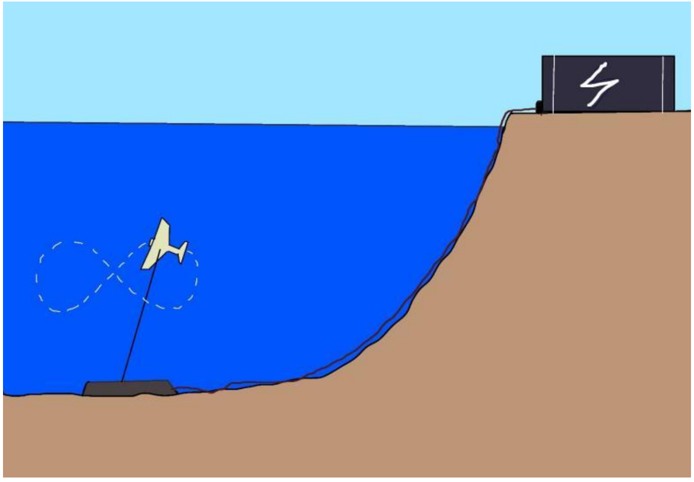

Fig 9. Underwater kites in operation.

4.4. Discussion and Limitation

To sum up, ocean current power generation technology, as a new renewable energy power generation method, has obvious advantages. As a kind of permanent energy, ocean currents have extremely abundant reserves and are characterized by stability and predictability. The use of ocean currents for power generation has broad prospects and high sustainability. However, up to now, the development and utilization of ocean currents are still very limited, and we can even say that they have not started yet, even though their potential is huge. The various ways of using ocean currents to generate electricity now cover various application scenarios and power conditions, which means that we can make full use of ocean current resources to generate electricity in different situations. Ocean current power generation technology has a relatively mature theoretical foundation. At this stage, it still needs to continue to carry out experimental tests to improve its reliability, economy, and environmental friendliness to strive for early use in large-scale commercial power generation.

However, the technologies related to ocean current power generation are still not mature enough, and the construction and maintenance costs of power plants cannot be accurately estimated. For underwater operation, the power generation equipment shall be hard and reliable to resist water pressure and well-sealed to prevent seawater leakage, to ensure the normal operation of its components. Seawater corrosion is also a major problem. The external surface of the power generation device shall be made of non-corrosive materials. For hydraulic turbines, various debris and artifacts in the water flow may cause serious damage to the blades. The noise generated by the power generation device is also a problem. Marine mammals may be stranded, change their behavior, and disturb their normal eating when exposed to excessive marine noise. In addition, as climate change disrupts the thermohaline mechanism, these ocean currents will slow down with global warming, so we need to stop climate change to make this technology work in the long run.

5. Conclusion

About wave energy generation, the cost of large-scale wave energy generation is still difficult to compete with that of conventional energy generation, but low-power wave energy generation for special purposes has been popularized and applied in navigation light buoys, lamp piles, lighthouses and so on. In the future, new devices should be further developed to improve the efficiency of wave energy conversion. To improve the density of wave energy, reduce the size of the device and reduce the cost. It is expected that with the depletion of fossil energy resources and the progress of technology, wave power generation will gradually occupy a certain position in countries rich in wave energy.

About tidal power generation, his single-cell two-way power generation method is the most widely used tidal power generation method at the current technological level. With the advancement of science and technology in the future, it is believed that the cost of dual-cell bidirectional power generation will be continuously reduced, and then it will become the mainstream of tidal power generation. Moreover, the development prospect of tidal energy in China is very optimistic. Although, due to the competition of cheap electricity charges from conventional power stations, not many commercial tidal power stations have been built and put into operation. However, due to the huge tidal energy reserves and many advantages of tidal power generation, people still attach great importance to the research and experiment of tidal power generation. Tidal energy is also one of the most potential energy sources in China in the next 20 years.

Ocean current power generation technology, as a new renewable energy power generation method, has obvious advantages. As a kind of permanent energy, ocean currents have extremely abundant reserves and are characterized by stability and predictability. The use of ocean currents for power generation has broad prospects and high sustainability. However, up to now, the development and utilization of ocean currents are still very limited, and we can even say that they have not started yet, even though their potential is huge. The various ways of using ocean currents to generate electricity now cover various application scenarios and power conditions, which means that we can make full use of ocean current resources to generate electricity in different situations. Ocean current power generation technology has a relatively mature theoretical foundation. At this stage, it still needs to continue to carry out experimental tests to improve its reliability, economy, and environmental friendliness to strive for early use in large-scale commercial power generation.

The marine new energy industry is conducive to improving environmental efficiency and contributing to the steady development of marine low-carbon economy. It has become an urgent need to develop marine new energy to replace traditional high-energy energy sources. Due to the high regional and low energy density of marine energy, the problems of high equipment construction and maintenance costs and low energy conversion efficiency are common in the marine new energy industry. In order to improve the efficiency of energy conversion and improve economic benefits, it also needs to rely on technological innovation and industrial technology progress.

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