Research on Power Control Method of Oscillating Float Type Ocean Wave Energy Power Generation

Ma Hongda*

College of Energy and Powering of Engineering, Wuhan University of Technology, Wuhan, China

*Corresponding author’s e-mail: 239159@whut.edu.cn

Abstract: With the development of the economy, human beings’ over-utilization and dependence on traditional energy sources such as oil, coal, and natural gas have gradually triggered a global energy crisis. Therefore, the use of renewable energy has received great attention from people, and the ocean that accounts for the total area of the earth has first come into the sight of developers. Wave energy has the advantages of wide distribution, large reserves, and diverse acquisition methods, and has become one of the most promising marine energy sources. However, the research on wave energy is currently in its initial stage and its development is relatively lagging. It is a renewable energy with great potential in order to increase the power generation of wave power systems. This article first introduces the current distribution of wave energy and outlines the principle of wave power generation. In view of the calculation method of wave force and the shortcomings of the current floating-type power generation system, a new type of oscillating floating-type wave power generating device is designed, which can realize the maximum power tracking control to a certain extent.

1. Introduction

With the depletion of petroleum and other petrochemical energy sources and the increasingly serious environmental pollution, the development and utilization of low-carbon, pollution-free renewable energy sources are becoming the theme of world energy development. More and more attention has been paid to sustainable energy, such as wind, solar, marine, and biomass. Therefore, renewable energy has become a current research hotspot, and the development of sustainable energy has become a top priority in the national energy strategies of many countries. The "Marine Energy Development" published by UNESCO believes that the theoretical renewable rate of global wave energy is about $3 \times 10^9$ kW, and the technologically available amount is about $1 \times 10^9$ kW, and the actual power that can be developed and utilized is about $3 \times 10^8$ kW [1]. Ocean wave energy is a new type of clean and pollution-free renewable energy, which has the characteristics of large reserves, wide distribution, high energy density, and easy energy conversion, as it has become a key research object. China has abundant wave energy resources, but compared to developed countries such as Europe and the United States, the research on wave energy started late. Therefore, many key technologies are still in the research stage, and relevant technical research needs to be vigorously carried out to fully develop and utilize wave energy resources. Wave power generation can alleviate the current situation of energy shortage and environmental pollution. Compared with other wave energy power generation devices, the oscillating float wave power generation device studied in this paper has the advantages of large energy density, small size and strong flexibility [2]. For island power supply, defense navigation and the exploitation of marine resources are of great significance. The wave changes at all times. How to
ensure that the oscillating float-type wave power generation system device can capture the maximum power stably under the actual complex sea conditions is a hot and difficult point of research. A new type of oscillating float-type wave power generation device is proposed, which has certain practical significance.

2. China's wave energy distribution

China is located in a region adjacent to the Eurasian continent and the Pacific Ocean. The territorial sea is mostly a closed, semi-closed marginal sea. The sea area is relatively closed, and the wind is small, and it has the characteristics of significant seasonal and sudden changes [3]. Table 1 shows the distribution of wind energy in China.

![Table 1. Distribution of wind energy resources in China](image)

| Main wind energy indicators | Rich area | Relatively rich area | Available area | Missing area |
|----------------------------|-----------|----------------------|----------------|-------------|
| Equivalent wind speed/(m/s) | 6.92      | 6.92~6.27            | <6.27~4.37    | <4.37       |
| Annual effective wind energy density/(W/m²) | >200 | 200~150 | <150~200 | <50 |
| >3m/s cumulative hours/h | >5000 | 5000~4000 | <4000~2000 | <2000 |
| >6m/s cumulative hours/h | >2200 | 2200~1500 | <1500~350 | <350 |
| Percentage (National) | 8 | 18 | 50 | 24 |

The state of wave energy resources depends on the state of the wave, especially the two factors of wave height and period.

Wave height distribution: In general, the literature shows that, except for overseas, China’s offshore is smaller in the north and larger in the south; the coast of the South China Sea is larger in eastern Guangdong and Xisha regions, and smaller in other regions; The most resource-rich areas [4]. The distribution of effective wave height also has obvious seasonal changes, and the trend is the largest in winter and the smallest in summer [5].

According to statistics such as the Survey of China's Coastal Rural Marine Energy Resources Zoning and the Outline of National Marine Functional Zoning, the distribution of wave energy resources in China's provinces is shown in Table 2:

![Table 2. Distribution of wave energy resources in various provinces and regions in China](image)

| Provinces and cities | Theoretical average power / MW | Percentage |
|----------------------|-------------------------------|------------|
| Jiangsu              | 291.25                        | 2.3        |
| Liaoning             | 255.03                        | 2.0        |
| Hebei                | 143.64                        | 1.1        |
| Shandong             | 1609.79                       | 12.5       |
| Shanghai             | 164.83                        | 1.3        |
| Zhejiang             | 2053.40                       | 16.0       |
| Fujian               | 1659.67                       | 12.9       |
| Taiwan               | 4291.22                       | 33.4       |
| Guangdong            | 1739.50                       | 13.5       |
| Guangxi              | 80.9                          | 0.6        |
| Hainan               | 562.77                        | 4.4        |
| Nationwide           | 128520.0                      | 100        |
This part of the bank section has a slightly higher energy flow density of 1.96 to 3.63 kW/m, and has small seasonal variation and tidal range. It is also small, with an average tidal range of less than 1 meter, and the coast is mostly bedrock harbors.

3. Wave power generation principle
Wave energy refers to the potential and kinetic energy possessed by ocean waves, and wave energy power generation refers to the conversion of uncontrollable kinetic energy in waves into electrical energy that is easier to use. The first stage is the wave conversion device WEC (Wave Energy Converter), which captures the kinetic energy of waves and converts it into mechanical energy [6]. The second stage is the energy capture device PTO (Power Take-off) Converting mechanical energy into electrical energy [7]. The entire power generation process of the device is shown in Figure 1.

At present, the oscillating float wave energy device is called the third generation wave power generation device, and its advantages are mainly reflected in:
- Because the device is in direct contact with the waves, the number of energy conversions is reduced, and the energy loss is reduced, and the energy conversion efficiency is relatively high;
- The area occupied by the unit is small, and its influence on the wave field can be ignored;
- The type of the device is more flexible, and it can be arranged in dot matrix according to different installed capacity requirements and wave energy distribution conditions. At present, the oscillating float-type wave power generation device mostly realizes the absorption of wave energy by means of single-degree-of-freedom movement of the absorber, multi-degree-of-freedom combined movement, and multi-absorber combination. The power conversion system focuses on linear motors and hydraulic motor systems.

The conversion of wave energy is divided into three parts: first-level conversion, intermediate conversion and final conversion, as shown in Figure 1. The first level of conversion is the most representative. It needs to adapt to the characteristics of wave energy, and the final conversion must meet the needs of users. Generally, the characteristics of the two are inconsistent [8]. Therefore, an intermediate conversion needs to be added as a bridge between the first-level conversion and the final conversion.

![Wave energy conversion system](image)

Figure 1. Wave energy conversion system

The first stage of conversion is to convert the kinetic energy of the vertical motion of the waves into the energy held by the power generation device. Therefore, a wave power generation device requires a pair of entities: an energy receiver and a stationary body. The recipient is in direct contact with the waves and receives energy from the waves. The stationary body is relatively fixed to the energy receiver, and forms a relative movement or a disparity with the energy receiver. The first-level
conversion of wave energy is achieved through the combination of the energy receiving body and the stationary body [9].

Intermediate transitions act as bridges, connecting the first-level transition to the final transition. The kinetic energy generated by the vertical motion of the wave, after the first stage conversion, still cannot meet the requirements of the power machinery for the final conversion. Intermediate conversion has the functions of increasing speed, steady direction, and stable speed. And there is still a distance between the first-stage conversion of offshore wave power generation equipment and power machinery, so the intermediate conversion also has the function of transmitting energy and storing energy. According to the different transmission entities, the intermediate conversion is divided into three types: hydraulic, mechanical and pneumatic.

The final conversion is the conversion from mechanical energy to electrical energy. Conventional technology generators with appropriate regulation mechanisms are generally used. Since the generator works with large changes, the efficiency will be affected. According to the different end uses, the final conversion may not be converted into electricity, but directly used in the situation of mechanical energy, so the power generation-electricity link is reduced, the structure is simplified, and the efficiency is improved.

4. Calculation method of wave force
The hydrodynamic pressure on the float in the waves includes three parts: the incident wave force caused by the incident velocity potential, the diffraction force caused by the diffraction wave potential, and the radiation force caused by the radiated wave potential. Among them, the acting force of the incident wave and the diffraction wave on the floating body is called the wave excitation force. Wave excitation force and radiation force are the two main components of wave load. Radiation force can be described by the hydrodynamic coefficient (additional mass coefficient and additional damping coefficient). The wave load calculation of the floating body can be transformed into solving the float the problem of wave forces on the body.

At present, the methods for calculating wave forces are mainly Morison method, Froude-Krylov method, and diffraction method. The three methods are applicable to different float structures. The Morison method is only applicable to relatively small float structures, that is, the float structure whose ratio of the diameter to the wavelength is less than 0.2. At this time, the influence of the presence of the float on the wave motion is ignored. For the calculation of the wave force of the float body with a relatively large wavelength, the influence of the float body on the wave flow field cannot be ignored. The wave diffraction and radiation effects caused by the float body must be considered. The calculation is based on the projection method. The diffraction method can relatively accurately calculate the wave force on the floating body, but the calculation method is more complicated.

The Froude-Krylov theoretical method is also called the Froude-Krylov hypothesis method, and it is also referred to as the F-K hypothesis method for short. The FK assumption method is based on the assumption that the presence of the floating body does not affect the wave pressure, and finds the force of the wave pressure on the floating body without interference. This force is referred to as the FK force. The radiation coefficient C (reflects the additional mass effect) is modified, and the corrected force is the wave force received by the float, which can be expressed as:

\[ F = CF_k \]  

(1)

Where C is the diffraction coefficient and F-K force is:

\[ F_k = \rho V_a \frac{dv}{dt} \]  

(2)

In the formula, \( \rho \) is the density of seawater; \( (dv / dt) \) indicates that the drainage volume is the average acceleration of the water body in Va without being disturbed. Because the acceleration of each water mass point in the drainage volume Va is different, it is difficult to obtain the average acceleration. Relatively speaking, the simpler method is to use the pressure of each water mass point when undisturbed to integrate the F-K force on the surface of the float body, and then multiply the corresponding diffraction coefficient to obtain the wave force acting on the surface of the float body. The component force and vertical wave component are calculated separately:
\[ F_x = C_H \int p_x n_x dS \quad (3) \]
\[ F_z = C_V \int p_z n_z dS \quad (4) \]

In the formula, \( p_x \) and \( p_z \) respectively represent the horizontal and vertical components of the wave pressure at any point on the surface of the float body without being disturbed; \( S \) is the total surface area of the float body immersed in seawater; \( C_H \) and \( C_V \) represent the horizontal and vertical diffraction coefficients, respectively.

The F-K assumption method is suitable for calculating the wave force when the float structure is large, and the calculation method is simple. Therefore, this article uses the F-K assumption method to calculate the wave force on the float body.

5. New type oscillating float type wave power generation device

Conversion efficiency includes two parts, namely the conversion process from wave energy to mechanical energy, and from mechanical energy to electrical energy. Due to the variability of waves and the inertia of mechanical devices, taking up the most energy from moving waves is a complex system control problem. For the study of efficiency problems, many experts have proposed solutions based on device design and optimization, but most of them are based on float design and optimization solutions. This paper proposes a new type of oscillating float-type wave power generation device. By adjusting the mass of the vibration mass and the output power (torque) of the generator, the vibration is placed in a "resonant" state to achieve maximum power capture of wave energy. Figure 2 is a flow chart of the working principle of the device.

![Figure 2. The flow chart of device](image)

It can be seen from Figure 2 that the new type of oscillating float type ocean wave power generating device includes an oscillating floating body, an oscillating mechanism, a mechanical transmission mechanism, a generator and a controller. The oscillating mechanism, the mechanical transmission mechanism, the generator and the controller are all installed in the oscillating floating body. The kinetic energy of the waves acting on the oscillating floating body is converted into the reciprocating linear motion mechanical energy of the mass in the vibration mechanism through the vibration mechanism. Through the rack connected to the lower end of the mass, the reciprocating linear motion mechanical energy is transmitted to the mechanical transmission mechanism. The driving gear and the pawl and ratchet system in the mechanical transmission mechanism convert the linear motion mechanical energy into rotating mechanical energy in a single direction and increase the rotation speed, thereby driving the low-speed permanent magnet synchronous generator to generate electricity. The AC power generated by the generator is transmitted to the PWM controller via a connection cable. After rectification and voltage control are performed through a rectifier bridge controlled by the PWM controller, power is supplied to the electric equipment, and the battery can be charged. The PWM controller can also be based on the situation that the floating body is affected by waves, the vibration mechanism absorbs wave energy, the output power of the generator, and the output power of the rectifier bridge. It adjusts the rectifier bridge switch tube in PWM mode to achieve the adjustment of generator output power. This measure further adjusts the damping of the vibration mechanism to realize the resonance operation of the vibration mechanism. Another adjustment measure is to change the mass of the mass, with a cavity inside the mass. This measure can change the
mass of the mass by injecting or extracting seawater. Among them, the inside of the seawater injection mass relies on the gravity injection of seawater, and the injection volume is controlled by a check valve, and the extraction of seawater is achieved by a water pump controlled by the controller. Both the check valve and the water pump are controlled by the controller.

6. Conclusion

Waves cannot be produced on a regular basis, and have the characteristics of strong energy but diffuse speed and periodic changes. The disadvantage of the existing wave power generation technology is that the inefficiency of the wave power generation system greatly affects the application of the wave power generation technology. In view of this situation, this paper proposes a new type of oscillating float-type wave power generation device. Based on the analysis of the structure and characteristics of the vibration mechanism, transmission mechanism and generator mechanism, this paper proposes an easy-to-implement maximum power tracking control method, which has certain practical significance.

References

[1] L. W. Gerald, R. S. Walter, Harvesting Ocean Energy, UNESCO, 1981.
[2] F.O. Antonio, Wave energy utilization: A review of the technologies, Renewable and sustainable energy reviews, 2010, vol.14, No.3, pp.899-918
[3] A.F.O. Falcão, J.C.C. Henriques, Oscillating-water-column wave energy converters and air turbines: A review, Renewable Energy, 2016, No.85, pp.1391-1424
[4] Z. Feng, E. C. Kerrigan, Latching control of wave energy converters using derivative-free optimization, 52nd IEEE Conference on Decision and Control, IEEE, 2013, pp.7474-7479
[5] S. Zou, O. Abdelkhalik, R. Robinett, et al., Model Predictive Control of parametric excited pitch-surge modes in wave energy converters, International journal of marine energy, 2017, No.19, pp.32-46.
[6] L. Li, Z. Yuan, Y. Gao, Maximization of energy absorption for a wave energy converter using the deep machine learning, Energy, 2018, No.165, pp.340-349.
[7] M. Y. Zheng, Research on the technology of oscillating float type wave energy power generation, South China University of Technology, 2017.
[8] K. D. Lin, Structural optimization and maximum wave energy capture control of point absorption wave power generation system, South China University of Technology, 2018.
[9] Y. Jiang, J. M. Yang, Z. K. Xie, et al. Segmental control of oscillating float wave power generation system, Renewable Energy, 2018, vol.36, No.12, pp.1794-1799.