Design and research on the simulation platform of Oscillating Flapping-Wing Wave Energy Converter based on AMESim

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Abstract. It is a stochastic dynamic process for conversion of wave energy, which includes the coupling of multiphysics. Energy conversion efficiency and stable output are important objectives. In order to explore the mechanism of wave energy efficient conversion, a wave energy generation scheme of oscillating-flapping wing was proposed. Taking the conversion system of wave power generation device as the research object, the mechanical-hydraulic-circuit simulation platform of the system is established by the software AMESim. The proposed scheme is tested and verified. The results show that the wave energy conversion system can effectively convert wave energy, realize the stable output of electric energy and store it in the battery pack, which provides a theoretical basis for the development of wave energy generation converter of oscillating-flapping wing.

1. Introduction
With the rapid development of the world economy and people's attention to the environment, there is an increasing demand for clean energy. The energy security has become a national development strategic issue [1]. The global wave energy potential reaches 10 TW, and the average annual wave energy is estimated to be close to 93000 TWh [2]. The development and utilization of wave energy has become a hot topic in many countries. Due to the object movement or oscillation caused by waves is very slow and has the characteristics of bidirectional and random irregular, it will lead to unstable power generation of equipment and poor output characteristics of the system. The equipment needed to cope with the harsh ocean climate is also expensive to manufacture. Up to now, the design of wave energy conversion system is still a technical difficulty.

In order to explore the mechanism of wave energy acquisition and efficient conversion, a wave energy generator with oscillating flapping wing was proposed. With oscillation wave energy power generation device of the flapping wing gathering and transfer system as the research object, research of wave energy power generation device simulation platform, focus on analysis of energy conversion systems and pluripotent domain joint simulation technology, and to stabilize the power in to efficiently implement as the main target, analysis and dynamics of the machine - hydraulic - electric joint simulation research.
2. Oscillating flapping-wing wave energy conversion system

An oscillating flapping-wing wave power generation converter with multi-cavity hydraulic cylinders mainly adopts a mechanical linkage mechanism to absorb energy. When the wave acts on the flapping-wing, it is connected to the connecting rod, and moves in pitch and heave. All can be converted into the rotary motion of the rocker arm link, thereby improving the energy acquisition efficiency of the flapping-wing. The connecting rod is also connected with a multi-cavity hydraulic cylinder. The cylinder is connected with the control valve group, accumulator, motor and other components through the hydraulic pipeline to form a hydraulic conversion system. Figure 1 shows the basic composition of the oscillating flapping-wing wave energy conversion system.

![Figure 1. Basic components of the oscillating flapping-wing wave energy conversion system.](image)

The system is an energy conversion system that integrates energy conversion, power generation, and energy storage. Its design principle is to achieve energy conversion stably, reliably and efficiently. And transmission, combined with accumulators and control components to form an independent wave power generation system to provide distributed power solutions for offshore platforms [3].

3. Design of conversion system

3.1. Hydraulic conversion system

The composition of the hydraulic conversion system is shown in figure 2. There are three solenoid valves in the circuit, each valve is connected to a chamber. The selection of different pressures in each chamber is controlled by the quick solenoid valve switch [4]. When the cylinder is in motion, each chamber can be controlled by valves to pass high or low pressure oil. According to the strength requirements, the diameter \( d \) of the piston rod must meet the following formula:

\[
d \geq 1.13 \left( \frac{F}{\sigma} \right) \zeta
\]  

(1)

Where \( F \) is the output force of hydraulic cylinder; \( \sigma \) is the allowable stress of piston material; \( \zeta \) is the safety factor, take 1.8.

When calculating the inner diameter of the hydraulic cylinder, the following formula must conform to:

\[
D = 1.13 \left( \frac{F}{P} \right)
\]  

(2)

Then query the national standard [5] to select the inner diameter of the hydraulic cylinder cavity. The output force of cylinders can reach the maximum value under normal operating conditions:

\[
F_{\text{max}} = (-P_{A1} \times S_{A1} + P_{A2} \times S_{A2} - P_{A3} \times S_{A3}) \times \eta \times \psi
\]  

(3)

Where \( P_{A1}, P_{A2}, P_{A3} \) are the pressure of each chamber; \( S_{A1}, S_{A2}, S_{A3} \) are the cross-sectional area of each chamber; \( \eta \) is the efficiency of the hydraulic cylinder, generally taken from 0.7 to 0.9; \( \psi \) is the load rate of the hydraulic cylinder, generally taken from 0.5 to 0.7. With the formula of cavity area \( S = (D^2 - d^2)\pi/4 \), the parameters of each cavity can be calculated.
In the operation of the hydraulic cylinder, the strength of the straight rod under the tension and pressure load is calculated by checking the formula:

$$\sigma = \frac{4F \times 10^{-6}}{\pi d^2} \leq \sigma_p$$  

(4)

![Figure 2. Components of the hydraulic conversion system.](image)

1. multi-chambers hydraulic cylinder 2. speed sensor 3. acceleration sensor 4. electromagnetic switch valves 5. high pressure accumulator 6. low pressure accumulator 7. high pressure accumulator 8. oil supply pump 9. oil tank 10. hydraulic motor 11. electric motor 12. generator 13. overflow valve 14. oil filter

When the force $F_1$ is on the axis, the bending stability of the piston rod is checked by the following formula:

$$F_1 \leq F_1 / n_k$$  \hspace{1cm} (5)

$$F_1 = \frac{2^2 E_1 I \times 10^6}{K^2 R_n}$$  \hspace{1cm} (6)

Where $F_1$ is the critical compression force of piston rod bending instability; $n_k$ is safety factor; $E_1$ is the coefficient, $E_1 = E / (1 + a) (1 + b)$, $E$ is the elastic modulus of steel. $a$ is the microstructure defect coefficient of material, generally taken $1/12$. $b$ is the non-uniformity coefficient of piston rod section, generally taken $1/13$. $I$ is the moment of inertia of the piston rod cross section; $K$ is the hydraulic cylinder installation and guiding coefficient; $L_B$ is the overall length of the cylinder.

### 3.2. Electric energy conversion system

The electric energy conversion system of the wave energy power generation device mainly includes a three-phase rectifier unit, a filtering and stabilizing unit, a DC/DC conversion unit, and a charging energy storage unit. Figure 3 shows the circuit diagram of the electrical energy conversion system.

![Figure 3. Circuit diagram of the electric energy conversion system.](image)

The rectifier part is mainly composed of three rectifier diodes connected to the common cathode of the upper bridge arm and three rectifier diodes connected to the common anode of the lower bridge arm [6]. The voltage range required by the charging unit is 120–168V, the Boost converter with boost function is selected here [7].

The phase current of the generator at rated power is:
\[ I = \frac{P}{\sqrt{3}U_2 \phi} \]  

(7)

Where \( \phi \) is the input power factor, \( P \) is the output power of the generator, \( U_2 \) is the phase voltage of the motor.

The capacitance value of the filter capacitor \( C_1 \) can be calculated by the empirical formula:

\[ C_1 = (5 \sim 8) \frac{1}{6f2R} \]  

(8)

Where \( f \) is AC power frequency, \( R \) is the equivalent load resistance.

The self-inductance at the minimum critical state of inductance is:

\[ L \geq \frac{U_E \alpha T}{2I_o}(1 - \alpha) \]  

(9)

Where \( U_E \) is the rectified voltage, \( \alpha \) is the duty ratio, \( T \) is the pulse period, \( I_o \) is average load current.

The relationship between the output filter capacitor \( C_2 \) and the output ripple voltage is:

\[ C_2 = \frac{U_E \alpha T^2}{\Delta U 8L} \]  

(10)

Where \( \Delta U \) is the ripple voltage.

4. Simulation platform and system performance analysis

In order to study the working state of the oscillating flapping-wing wave energy power generation device, the simulation platform of the system was established by AMESim simulation software, the parameters of each component were set [8]. The efficiency and stability of the oscillating flapping-wing power generation system are analyzed [9]. The energy is transferred through the hydraulic system, and finally the hydraulic motor is driven to rotate. As shown in figure 4, it is a hydraulic conversion system model. In the electric energy conversion system, the rotation speed of the motor is used as the input to simulate the working condition of the system. Figure 5 shows the electric energy conversion system model.

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Figure 4. Model of the hydraulic conversion system.
In the hydraulic energy conversion system, the motion characteristics of the flapping wing under the action of waves are used to control the swinging speed and angle of the rocker arm, so as to realize the movement of the rocker arm to drive the piston rod to do telescopic movement [10]. The characteristics of four-level waves (wave height is 2m, period is 5s, water depth is 30m) are selected as the input signal of the system, as shown in figure 6 and figure 7. The charging power of the battery pack under level 3, 4 and 5 sea conditions is shown in figure 8 and figure 9.

Taking the movement time of the flapping-wing from one trough to the next as a sampling period, the work done by the flapping-wing by external forces such as waves and gravity during this process is equal to the change in the potential energy of the flapping-wing, the average power absorbed by the flapping wing is:
\[ P_w = \frac{\Delta E}{\Delta t} = \frac{\Delta E_k + \Delta E_p}{\Delta t} \]  

Where \( E_k \) is the kinetic energy of the flapping-wing, \( E_p \) is the potential energy of the flapping-wing.

The input power formula of the lithium battery pack can get its average input power:

\[ \eta_1 = \frac{P_{g(out)}}{P_w} \]  

Where \( P_{g(out)} \) is the average output power of the generator.

The energy storage efficiency of the electric energy conversion system of the oscillating flapping-wing wave energy power generation device is:

\[ \eta_2 = \frac{P_{in}}{P_w} \]  

Where \( P_{in} \) is the average input power of lithium battery pack.

Through the analysis of the simulation results, the energy storage efficiency of the flapping-wing wave energy power generation device under different sea conditions is shown in table 1.

| Sea states | The flapping-wing absorb power/kW | The generator output power/kW | The battery input power/kW | Power generation efficiency \( \eta_1 \) | Energy storage efficiency \( \eta_2 \) |
|-----------|----------------------------------|-------------------------------|---------------------------|---------------------------------|---------------------------|
| Level 3   | 17.3                             | 7.3                           | 6.0                       | 42.2%                           | 34.7%                     |
| Level 4   | 28.1                             | 11.4                          | 7.1                       | 40.6%                           | 25.3%                     |
| Level 5   | 25.8                             | 11.2                          | 7.1                       | 43.4%                           | 27.5%                     |

5. Conclusion

In order to solve the problem of stable power generation by ocean wave energy, a design scheme of an oscillating flapping-wing wave energy power generation converter was proposed. A simulation platform was built based on AMESim, and the energy conversion of the oscillating flapping-wing wave energy power generation system under different sea states was analyzed.

It is verified that the power generation converter scheme meets actual needs, and the multiple solenoid valves in the hydraulic circuit of the system respectively control the oil pressure of each chamber of the hydraulic cylinder, which can realize rapid switching of different circuits and has the advantage of shorter response time. The electric energy output by the generator is converted, and the battery can be used to store electric energy continuously and stably. Users can flexibly adjust the battery according to the actual situation.

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