Design and Implementation of Energy Saving System for Electric Propulsion of Unmanned Vehicle

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Abstract. Ocean exploration technology has become a key technology in the research and development of countries all over the world. As a new intelligent platform for ocean exploration, unmanned ship has also become one of the important equipment of ocean exploration technology. At the same time, in response to the call of global green energy, the application of energy-saving technology and new energy schemes in unmanned ship electric propulsion system has increasingly become a hot area of ocean exploration technology. In this paper, the electric propulsion system of unmanned ship is designed based on photovoltaic technology, and the mathematical modeling and simulation experiments of the system are carried out. The experimental results show that the proposed UAV electric propulsion system has obvious advantages in energy saving compared with the traditional UAV electric propulsion system. At the same time, the energy-saving electric propulsion system proposed in this paper also has strong dynamic performance and stability performance.

Keywords: Ocean exploration technology; Unmanned Vessel Electric Propulsion System; Photovoltaic power generation technology; Green energy.

1. Introduction
With the increasing attention of all countries in the world to the field of ocean exploration, a large number of ocean exploration equipment are constantly emerging. As a product of information technology and artificial intelligence technology, UAV is a very advanced intelligent platform for ocean exploration [1-3]. However, with the call of global green energy concept, the energy-saving propulsion system of unmanned aerial vehicles has increasingly become the research focus of researchers and institutions in various countries. The research and development of energy-saving propulsion system for unmanned aerial vehicles is not only conducive to solving the current global energy shortage situation, but also conducive to alleviating the current problem of increasing marine pollution [4-6]. Therefore, it is of great significance and practical value to effectively integrate new energy technologies in unmanned ship propulsion system.

Based on the above marine strategy and the status quo of UAV propulsion system, scholars and research institutions in various countries have done a lot of research and Analysis on its energy-saving technology. The earliest proposal to add solar energy technology to the marine power system was put forward by the relevant research institutes of the United States, but due to the technical limitations at that time, solar energy technology did not integrate into the marine power system very well [7]. German
research institutes have proposed solar energy and sail-aided energy-saving technology, which is assembled on a large oil tanker. This technology has achieved better energy-saving purposes, but the corresponding efficiency and system stability still need to be improved [8]. Relevant scientific research institutions in China have applied wind power technology to ship power system, which has achieved energy saving to some extent, but the instability of wind technology makes the whole power system also have instability factors [9]. In addition to the basic research mentioned above, there are many related studies such as the application of superconducting energy storage system to marine power system [10-13].

In order to solve the energy-saving problem of UAV propulsion system, this paper will study the power propulsion system of UAV based on photovoltaic technology, and make a mathematical model of the system. In the end, the traditional UAV propulsion system is compared with the energy-saving UAV propulsion system in this paper. The experimental results show that the energy-saving UAV propulsion system proposed in this paper has greater energy-saving advantages, as well as better performance in system stability and dynamic performance.

The structure of this paper is as follows: Section 2 will specifically introduce the combination of photovoltaic technology and UAV propulsion system, and carry out mathematical simulation; Section 3 will simulate the model of Section 2 and compare it with traditional UAV electric propulsion system; Finally, a summary and Prospect of this paper will be made.

2. Analysis and Modeling of Electric Propulsion System for Energy-saving Unmanned Vehicle

This section will focus on the analysis of the application of photovoltaic power generation technology in the unmanned ship power system, and its design process and principle are analyzed and studied, at the same time, based on the application of mathematical modeling analysis.

2.1. Application of Photovoltaic Power Generation Technology in Unmanned Vehicle Electric Propulsion System

This section will elaborate the principle of photovoltaic power generation technology under ship power system and carry out system modeling.

In this paper, photovoltaic array technology is used in unmanned ship power system. Figure 1 shows the equivalent circuit of the corresponding photovoltaic array model. The corresponding photovoltaic cell can be approximately regarded as a current source which is controlled by the solar illumination and temperature. In order to meet the corresponding load requirements of the electric propulsion system of unmanned aerial vehicle, a large number of photovoltaic battery arrays are integrated in parallel to realize photovoltaic battery arrays.

![Figure 1. The equivalent circuit of the corresponding photovoltaic array model](image)

The corresponding mathematical formula of photovoltaic array in Figure 1 is shown in Formula 1-4. The corresponding Io represents the saturated current value of the diode of the whole system, the corresponding Ic represents the light intensity S of the photovoltaic array and the corresponding short circuit current value at room temperature, the corresponding voltage V is the output voltage value, and
R1 and R2 represent the equivalent resistance of the system. Formula 3 corresponding to Formula 1-4 represents the diode characteristic equation of the whole system.

\[ I = I_g - I_d - I_s \] (1)
\[ I_s = \frac{V + I(R_1 + R_2)}{R_s} \] (2)
\[ I_d = I_o [\exp\left(\frac{V + IR_s}{nkT_c/q}\right) - 1] \] (3)
\[ I_g = I_s \frac{G}{G_r} \left[ 1 + \alpha (T_c - T_{o}) \right] \] (4)

In this paper, the output characteristic curves of YGE140 series photovoltaic modules are simulated based on the above characteristic equations of photovoltaic cells, and the corresponding power and output voltage curves are obtained. As shown in Figure 2, the output power is proportional to the intensity of receiving light.

![Figure 2. The output power is proportional to the intensity of receiving light](image)

In order to meet the special requirements of unmanned ship ocean exploration, the maximum power matching calculation is needed. In this paper, MPPT control algorithm is introduced to realize the maximum power matching of photovoltaic modules. In the actual application process, the corresponding maximum power matching algorithm structure diagram is shown in Figure 3. From the diagram, it can be seen that the control module will output the output voltage and current of photovoltaic cells by feedback, which is solved by MPPT algorithm module. When the MTTP algorithm module finds the corresponding maximum power point, it will output its power point. The reference value of the output power point voltage is compared with the output voltage of the photovoltaic array and PI is adjusted. Finally, the adjusted value is output to the pulse modulator to realize the control and monitoring of the electric propulsion system of the photovoltaic battery pack of the unmanned ship.
2.2. Modeling of Key Modules of Unmanned Vehicle Electric Propulsion System Based on Photovoltaic Power Generation Technology

Based on the above principles and control analysis of photovoltaic power generation technology, the following key modules of its application in unmanned ship propulsion system are modeled.

3. Model of photovoltaic governor

As shown in Figure 4, the model frame diagram of the corresponding photovoltaic power generation speed regulation system can be seen from the diagram that the core of the governor is the engine speed regulator based on the control algorithm. The corresponding mathematical formula of the controller is shown in Formula 5. The corresponding $U_t$ represents the output of the whole speed regulation system, $K_p$ is the corresponding proportional amplification constant coefficient, and $T_i$ is the integral time of calculus.

$$U(t) = K_p[e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt}]$$

The corresponding model equation of the whole photovoltaic power system is shown in equation 6. The corresponding $T_d$ is the dynamic factor of the whole photovoltaic power system, the corresponding $T_g$ is the resistance factor of the power system, and the corresponding $T_f$ is the friction factor.

$$J \frac{d(w + \Delta w)}{dt} = (T_j + \Delta T_j) - (T_j + \Delta T_j) - (T_j + \Delta T_j)$$
4. Mathematical Model of Propulsion Motor
As the energy acceptance and conversion terminal of photovoltaic power generation system, propulsion motor is mainly composed of three-phase asynchronous motor rotor and stator. Its corresponding physical model is shown in Figure. 5. The corresponding winding voltage, current and flux linkage follow the right-handed helix rule.

![Figure 5. The corresponding physical model](image)

The corresponding mathematical expression of the motor model is shown in Formula 7. The corresponding \( u \) represents the voltage matrix of the whole motor system, the corresponding \( I \) represents the current matrix, the corresponding \( L \) represents the inductance matrix, and the corresponding \( R \) represents the resistance matrix.

\[
u = R_i + L \frac{di}{dt} + w \frac{\partial L}{\partial \theta} i \tag{7}\]

Based on the above modeling, the modeling and analysis of key modules of UAV propulsion system under photovoltaic power generation technology has been realized, which will lay a theoretical foundation for the experimental part of the third section.

5. Simulation and Data Analysis
In this paper, the evaluation model is mainly based on the analytic hierarchy process in the actual simulation process. The main evaluation indicators involved are technical maturity, energy efficiency, energy loss per unit transport volume, carbon dioxide emissions per unit transport, the proportion of transportation cost per unit and the corresponding maintenance proportion. In the actual simulation, the case selected in this paper is a 200,000-ton large tanker, whose routine is set at 300 nautical miles. Based on the above parameters, the simulation results are shown in Table 1 below.

| evaluating indicator                                      | Unit value        | Traditional Unmanned Vehicle Propulsion System | propulsion system of unmanned ship presented in this paper |
|-----------------------------------------------------------|-------------------|-----------------------------------------------|------------------------------------------------------------|
| Technical maturity                                        | W.h./mile         | 0.331                                         | 0.301                                                      |
| Energy efficiency                                         | W.h./mile         | 1.112                                         | 0.908                                                      |
| Energy Loss Corresponding to Unit Transportation Volume    | W.h./mile         | 34.9                                          | 32                                                         |
| Carbon dioxide emissions per unit of transport             | Co2.kw./h         | 0.031                                         | 0.028                                                      |
| Proportion of unit transportation cost                     | %                 | 6.3                                           | 3.1                                                        |
| Maintenance proportion                                    | %                 | 5.2                                           | 3                                                          |
From Table 1, we can see that the energy-saving UAV propulsion system proposed in this paper has obvious advantages in energy saving, and it also has great improvement in emissions compared with the traditional diesel propulsion system. In order to embody the stability and good dynamic performance of the electric propulsion system of unmanned ship based on photovoltaic power generation technology proposed in this paper, it is compared with the traditional diesel propulsion system by simulation. The corresponding harmonic analysis curve is shown in Figure 6. It can be seen from the figure that the propulsion system proposed in this paper has good dynamic performance and stability performance.

![Figure 6. The corresponding harmonic analysis curve](image)

6. Future work and conclusions
In order to solve the energy-saving problem of UAV propulsion system, this paper studies the power propulsion system of UAV based on photovoltaic technology, and carries out the mathematical modeling of the system. In the end, the traditional UAV propulsion system is compared with the energy-saving UAV propulsion system in this paper. The experimental results show that the energy-saving UAV propulsion system proposed in this paper has greater energy-saving advantages, as well as better performance in system stability and dynamic performance. In order to further optimize the application of photovoltaic power generation technology in the electric propulsion system of unmanned ship, the later research work of this paper will focus on the further optimization of the stability and dynamic performance of its control system, and explore the application of this technology in a wider range of fields.

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