Research on Solar-assisted Ocean Thermal Energy Conversion System

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Abstract: At present, the Ocean Thermal Energy has low circulating thermal efficiency and poor power supply stability, so it has not been widely applied. To solve this problem, the combined generation system of ocean temperature difference energy and solar auxiliary heat is proposed. The multi-curved compound trough collector absorbs solar radiation energy, and layers heat exchange and energy storage with heat storage tank using heat conduction oil as medium. Then, the hot water storage and working medium preheated by warm sea water are used for efficient heat exchange in PCHE, so as to improve the system's power generation efficiency and improve the continuity of power supply. The Solar-assisted Ocean Thermal Energy Conversion System is established by using Aspen Plus. The theoretical calculation and simulation analysis of each part of the system were carried out, and the thermal cycle with R717 as the working medium was determined. With Sansha City of Hainan Province as the background, the design is based on the installed capacity of 130kW solar auxiliary heat ocean temperature difference power generation system to verify the feasibility of the project. The energy management device takes PLC as the core, according to the load demand and the predicted power generation, through the fuzzy PID control strategy to adjust the flow of working medium and cold and hot source, and manage the power generation system. The energy management device effectively solves the intermittent problem of OTEC cycle power generation and the lack of power performance under the condition of sudden increase of power load, and realizes the system's all-weather stable operation. Based on the traditional form of ocean temperature difference power generation, this system proposes the integration of solar energy efficient heat collection, heat storage and ocean temperature difference energy combined power generation technology, which greatly improves the system power generation efficiency and has high popularization and application value.

1. Introduction

With the development of social economy, the consumption of fossil energy is increasing day by day, which brings serious environmental pollution. The utilization of renewable clean energy will be an important way to solve the problem of energy shortage and environmental pollution, and the continuous promotion of the development and utilization of new energy will be the main trend of future development. In this context, coastal countries pay close attention to the ocean temperature difference energy, which is famous for its features of renewable energy, huge reserves and clean and pollution-free [1].

As a major maritime country, China has a huge reserve of Marine thermal energy resources in low-latitude waters, about 367 million kW, accounting for 1/14 of the global reserve of Marine thermal energy. The surface water temperature of the ocean is above 25℃, and the deep water temperature of 500~800 meters in the same sea area is below 5℃. OTEC (Ocean Thermal Energy Conversion) is the use of surface and deep-sea water temperature can make the working medium of the heat exchanger

after heat transfer to drive the turbine power generation technology, in the process of generating no emissions pollution and low raw material cost, clean and renewable, by-product is rich. Under the situation of energy conservation, emission reduction and low carbon development, the active development of Marine thermal energy resources can effectively solve the situation of energy shortage in China's coastal areas, especially for China's economic development and national defense construction in the South China Sea region, and accelerate the realization of the strategy of maritime power [2].

It is reported that the 50kW Ocean Thermal Energy Conversion System in Kumi Island, Okinawa Prefecture, Japan, successfully generated electricity for the first time in March 2013.In August 2015, the 100kW Ocean Thermal Energy Conversion System on Hawaii Island was successfully connected to the grid for power generation, and became the main way to use new energy sources for power generation. The French Island of Reunion will also deliver the 100-150MW high-power OTEC power plant group in 2025.The State Oceanic Administration of China has carried out the project of "Research and Test of Ocean Temperature Differential Energy Development and Utilization Technology", which is committed to improving the thermal efficiency of ocean temperature differential power generation. Currently, it is in the research and development stage, and there is no relevant report on the Ocean Thermal Energy Conversion System considering the introduction of solar auxiliary heat.

Figure 1. Traditional Ocean Thermal Energy Conversion System

2. Design of Solar-assisted Ocean Thermal Energy Conversion System

2.1. The overall structure design of the system

The Solar-assisted Ocean Thermal Energy Conversion System is mainly composed of solar auxiliary heat module, OTEC power generation module and PLC energy management module. The structure of the system mainly includes solar collector, heat exchanger, working fluid pump, expander, heat storage tank, heat conduction oil tank, pipeline and related valve parts.

2.2. The Solar-assisted module

Project selection set high thermal performance, the technology is relatively mature new surface composite trough type solar collector, the traditional single surface focus into focus of curved surface, make the high temperature solar receiver by focusing on the up and down sides of heating, improve the collection efficiency of receiver, and makes the thermal focal line is transferred to the bottom of the device, the installation and insulation of the receiver. At the same time, the high efficiency heat storage water tank is developed. Three layers of heat exchange coils are designed and installed inside the water tank to form high temperature zone, transition zone and low temperature zone from top to bottom, among which the high temperature zone is the main energy storage area. The water tank is equipped with three layers of walls, the internal use of silicate felt board and phenolic foam insulation board, to prevent heat loss, the outermost selection of Hastelloy C-276 alloy board, to avoid the corrosion of the heat storage tank under the Marine environment. The internal pressure of the water tank is maintained at about 4.8bar by the pressure limiting valve, which not only improves the boiling point of circulating fresh water, but

also avoids the influence of cavitation on the system. The design of layered heat storage and insulation layer greatly improves the heat storage efficiency of the heat storage tank, and ensures that the system can operate stably in the operation mode of power extraction at night, so as to realize the system's all-weather efficient power generation. The heat storage tank is equipped with temperature sensor, pressure sensor, PLC will collect the signal processing, by adjusting the corresponding valve bypass opening to change the flow size of the oil and water heat exchange, so that the temperature and pressure in the heat storage tank to maintain at a safe level [3].

2.3. OTEC power generation module

After the saturated liquid phase working medium is adiabatically compressed by the working medium pump, it is transported to the spiral plate preheater to exchange heat with the surface temperature seawater of 25-30℃. After isobaric heat is absorbed, it enters the evaporator, and the warm seawater is discharged from the preheater. The circulating fresh water in the hot water regenerator is heated by the heat conducting oil into high temperature heat source water, and then flows into the evaporator to conduct efficient heat exchange with the working medium in the wet steam state in PCHE. After further heat absorption in the evaporator, the working medium becomes superheated gas and enters the expander for adiabatic expansion.

Based on SVPWM induction motor vector control system, by adjusting the speed of the working medium pump, the working medium superheat is controlled to improve the stability of the evaporator and the expander working conditions, so that the system can obtain a higher heat conversion efficiency.

After the superheated working medium gas enters the expander, it expands into a high-speed flow through the nozzle and flows through the moving blade on the rotor of the expander to push the impeller of the expander to rotate. The rotor in the expander is connected with the rotor of the generator through a coupling. When the rotor of the expander rotates at a certain speed, the rotor of the generator rotates with it, causing alternating current to be generated in the stator coil. In addition, the expander is equipped with a lubricating oil system to achieve lubrication and cooling of the machine.

3. Energy management device

The energy management module is composed of power station short - term output power forecast system and control system. The short-term output power forecast system of the power station collects real-time environmental parameters (solar irradiance, temperature, etc.). According to the similarity day selection algorithm, the sample with the highest similarity is selected from the historical database as the predicted value of the output power of the system on that day.ABBAC500 series PLC as the core of control system, the collection and the running parameters and the output power prediction module, the fuzzy PID control strategy, adjust the working medium and heat and cold source flow, effectively solve the OTEC cycle power generation is intermittent and power load spurt the shortage problem of power performance, under the condition of implement system of continuous stable output power. Combining PID control with fuzzy control, the fuzzy PID controller is used to set three parameters of PID control, and the control effect is improved. PLC and man-machine interface combination can give full play to the PLC powerful work efficiency and performance as well as the HMI technology intuitive and easy to monitor the advantages, so as to improve the overall system of human-machine interaction and control performance [4].

Figure 2. Touch-screen man-machine interface

The functions of the system include: data acquisition and display, short-term output power forecast, operating condition adjustment, state monitoring and reminder, data storage and report form output.

(1) Data acquisition and display: real-time monitoring and display of system working parameters, convenient for operation and management of personnel;

(2) Short-term output power prediction: the real-time environmental parameters at the location of the power station (solar irradiation intensity, temperature, sunshine time, etc.) are transmitted to the output power prediction system for processing, and the output power of the system at each time period of the day is predicted;

(3) Operating condition adjustment: after obtaining the monitoring data, the touch screen button on the upper display is used to control the speed of each conveying pump and the opening of the temperature control valve, adjust the flow of working medium and cold and hot source, and realize the continuous and stable operation of the system under varying operating conditions;

(4) State monitoring reminder: monitor the working state of the system. When the parameters are abnormal, the control system will immediately protect and send an alarm;

(5) Data storage and report form output: it is convenient for the staff to query and analyze the historical data, provide parameter guidance for the optimization and improvement of the system, and establish a database to store and manage the historical data of the ocean temperature difference energy power station.

4. The key technology

(1) In view of the technical pain points of the current OTEC system, such as low circulating heat efficiency and poor stable power output capacity, the multi-curved composite collector is adopted to absorb solar radiant energy and layered heat exchange and energy storage with the heat storage tank using heat conduction oil as the medium to ensure the long-term supply of high-temperature hot water storage and realize the system's all-day efficient operation.

(2) In order to improve the heat transfer efficiency, the printed circuit plate heat exchanger (PCHE) with compact heat transfer core and high surface density is adopted. The heat transfer runner is easy to form intense turbulence, which increases the heat transfer coefficient and realizes the high efficiency heat transfer between hot water storage and working medium.

(3) With the PLC as the core of power management devices, power, environmental parameters based on real-time load and the historical weather data to predict the future power, using fuzzy PID control strategy, integrated management of solar energy auxiliary heat, water cooling and heat sources, and working medium flow rate, effectively solve the OTEC cycle power generation is intermittent and the power performance under the condition of power load sudden shortage problem.

5. Project innovation

(1) Proposed the ocean temperature difference combined power generation technology integrating solar energy efficient heat collection and storage, which improved the primary energy utilization efficiency

and increased the thermal efficiency of the OTEC cycle by 84.50% compared with the current demonstration application;

(2) The hot water storage and working medium adopt PCHE efficient heat exchange to improve the superheat of working medium before entering the expander and ensure the efficient operation of the expander;

(3) Aiming at the intermittency of OTEC cycle power generation and the lack of power performance under the condition of sudden increase of power load, a set of energy management device was developed to realize the system's all-weather continuous and stable power supply by adjusting the flow of solar auxiliary heat, seawater cold and heat source and working medium [5].

6. Conclusion

In order to meet the energy demand of economic development and national defense construction in coastal areas of China, and to further accelerate the strategic goal of building a maritime power, we must rely on the unique geographical conditions of the South China Sea to vigorously develop Marine temperature difference energy resources. Solar-assisted thermal ocean thermoelectric power generation system aims to further improve the power generation efficiency of the circulation system, enhance the value of the development and utilization of low-grade ocean thermoelectric energy, and break through the current situation of low primary energy utilization efficiency, which has a certain prospective. This work has the characteristics of reasonable structure, perfect function and high degree of automation. Compared with the traditional power generation method, it has outstanding effect of energy saving and emission reduction. If it can be popularized and applied on a large scale, it can effectively meet the urgent demand of electricity for economic development and national defense construction in the South China Sea region of China, and it has a good development prospect.

References

[1] Chen Fengyun. Research on Thermal Performance and Comprehensive Utilization of Ocean Temperature Differential Energy Generator [D]. Harbin Engineering University,2016.

[2] Liu Weimin, Ma Changlei, Chen Fengyun, Liu Lei, Ge Yunzheng, Peng Jingping, Wu Haoyu, Wang Quanbin.Progress in Marine renewable energy development and utilization and technology [J]. Advances in Marine Science,2018,36(01):1-18.

[3] Zheng Hongfei, Tao Tao, He Kaiyan, Kang Huifang.Journal of Engineering Thermophysics,2011,32(02):193-196.

[4] Adiputra R, Utsunomiya T, Koto J, et al. Preliminary design of a 100 MW-net ocean thermal energy conversion (OTEC) power plant study case: Mentawai island, Indonesia[J]. Journal of Marine Science & Technology, 2019.

[5] Bureau Veritas (2018) Classification and certification of ocean thermal energy converter (OTEC). Bureau Veritas, France.