RESEARCH ARTICLE

Multi-Energy System Based on Ocean Thermal Energy Conversion

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The ocean thermal energy is abundant. The global total is about 40 billion kW. The ocean thermal energy conversion (OTEC) is clean and renewable, the power generation is stable, and the energy storage has high capacity. Active exploitation of ocean thermal energy resources is of great significance to realize the strategy of maritime power. In view of the efficiency limit of a traditional OTEC, authors propose an approach of a multi-energy complementary OTEC system that they can improve the efficiency of this system. The approach sets parameters at the system level and integrates solar energy, wind energy, energy storage and OTEC. For example, a 1MW integrated power generation system is designed and simulated by means of computer aided design and of conducting a model-based simulation, respectively. The efficiency of the complementary OTEC system with solar heating can reach 13.12%. In this article, the basic principle and working process of the approach are analyzed, and the system efficiency is calculated. The results show that, in comparison to the traditional OTEC, the complementary system of OTEC can improve the ratio of power generation output efficiency, stability and ocean energy utilization.

Introduction

In the modern times, the world's energy consumption is rapidly increasing, fossil energy is decreasing, environmental pollution and greenhouse effect are becoming more and more serious to affect our daily lives. Therefore, the renewable energy has played an important role to change the energy infrastructure and maintain the long-term development of human energy utilization. According to the statistics, the temperature of the water 1000m below 24° latitude from the equator is about 4°C, and the temperature of the sea surface water is about 30°C. The potential energy from the temperature difference between the deep-sea and sea surface waters is about 10^{13}W [**1**]; the annual generating potential of ocean thermal energy is about therefore 87600TWh. In comparison, the global annual electricity demand is about 16000TWh [**2**]. Moreover, it is renewable, stable, clean and pollution-free, and has high development and utilization value.

The vast ocean power is a huge resource to tap into for the world. The OTEC system generates electricity by driving a thermodynamics Carnot heat engine between warm seawater and cold deep seawater. The concept of OTEC system has rendered an advanced green energy technology with a century-old of history. It has been well known historically that the oceanic resources are of immense economic value [**3-4**]. The atmospheric deposition in some case carries critical nutrients, e.g., that dust carries iron, phosphorous, nitrogen that are critical to the ocean eco-system.

The OTEC technology was initially proposed in 1881 by a French physicist Jacques Arsene1; at a later time， Dr. Georges Claude demonstrated the OTEC in 1924 [**5-6**]. Claude implemented an OTEC system in an industry scale in Matanzas Bay, Cuba. Going after the initial success, many development projects were accomplished between 1950 and 1960 by several research organizations. In 1964, American scientist J. H. Anderson et al. designed a new type of the closed-cycle "ocean thermal energy conversion" (OTEC) power station. Moreover, a new era of OTEC was propelled due to the needs for energy on the backdrop of the oil crisis in 1970s. The US Department of Energy has funded an OTEC program since 1970s, and later a wind program extending that one from the late 1970s to the present [**7**]. The OTEC is one of the significant energy resources that can play a prominent role in the future. There are significant milestones demarcated by previously successful engineering and demonstration projects [**7-8**].

The recent developments of the OTEC projects have proposed significant upgrade to deliver many mega-watts in power output [**9-10**] that has attracted extensive international collaborative efforts among which there are lots of the public and private partnership [**11-13**]. The open-cycle OTEC has attracted exciting research by scientists around the world that can improve the efficiency to 5% and above. Furthermore, in addition to the near shore projects [**14-15**]; there are off-shore OTEC project and big island project in development. Moreover, interesting works [**16-17**] are reported to predict health effect of Aerosol, particularly related to the seaborne issues and risks associated due to oceanic bound aerosol. Studies of the marine environment, environmental and air protection control is in progress so as to learn about the impacts on the terrestrial and marine eco-system. Authors will keep detailed studies on the ocean eco-system in the future. Finally, various aspects including potential environmental factors [**6,16-18**], costs and economics are studied in various model [**19,20**].

Since 2008, significant progress has been made in the research of some key technologies and small-scale demonstration of thermoelectric generators has come a long way. In terms of ocean thermal energy simulation and experimental research, domestic and foreign researches are also very active [**21-24**]. At present, the research on the optimization design of ocean thermal energy system has attracted extensive attention from domestic and overseas scholars. In order to improve the efficiency of ocean thermal energy generation system, Hakan Aydin *et. al.*, [**25**] introduced solar complementary heat, significantly increased the gas temperature at turbine inlet, and increased the energy output by 20% ~ 22%. Setiawan *et. al.*, [**10**] studied the effect of heating warm seawater with plate solar energy in a 33MW OTEC system by combining solar energy with OTEC, and the results showed that the introduction of solar energy could improve the thermal efficiency of the system, but at the same time brought about a series of system matching problems.

The research on ocean thermoelectric power generation system has made great progress, but it has not yet been in the mainstream for the energy generation. The main reasons are as follows: 1) The efficiency of traditional single OTEC system is low, which is generally 1%; 2) It is difficult and expensive to extract cold seawater from the 800m~1000m deep sea [**26**]; 3) At the same time that deep ocean water is released into the surface ocean, microbes from the bottom are released into the ocean surface, and may trigger changes in the ecosystem. In order to fully address above problems, this paper presents a 1MW ocean thermal energy conversion system based on the island conditions in the South China Sea; it studies the integration of clean, efficient and pollution-free solar energy, wind energy and energy storage system into the OTEC system. The OTEC system uses ammonia as the working fluid and uses solar heating technology to raise the working fluid temperature at the turbine inlet to 70°C, consequently the system's power generation efficiency is increased to 13.12%. So as to form an efficient, stable, clean and pollution-free integrated power generation system.

Designs and Models

The overall design and principle of system

As shown in **Fig. 1**, the overall design is mainly composed of four parts, including solar-boosted ocean thermal energy conversion (SOTEC) plant, freshwater system, wind-solar complementary system and energy storage system. Under sunny or windy conditions, the photovoltaic cell or universal wind generator generates electricity. Part of it supplies the initial power of the SOTEC system to ensure the normal operation of the

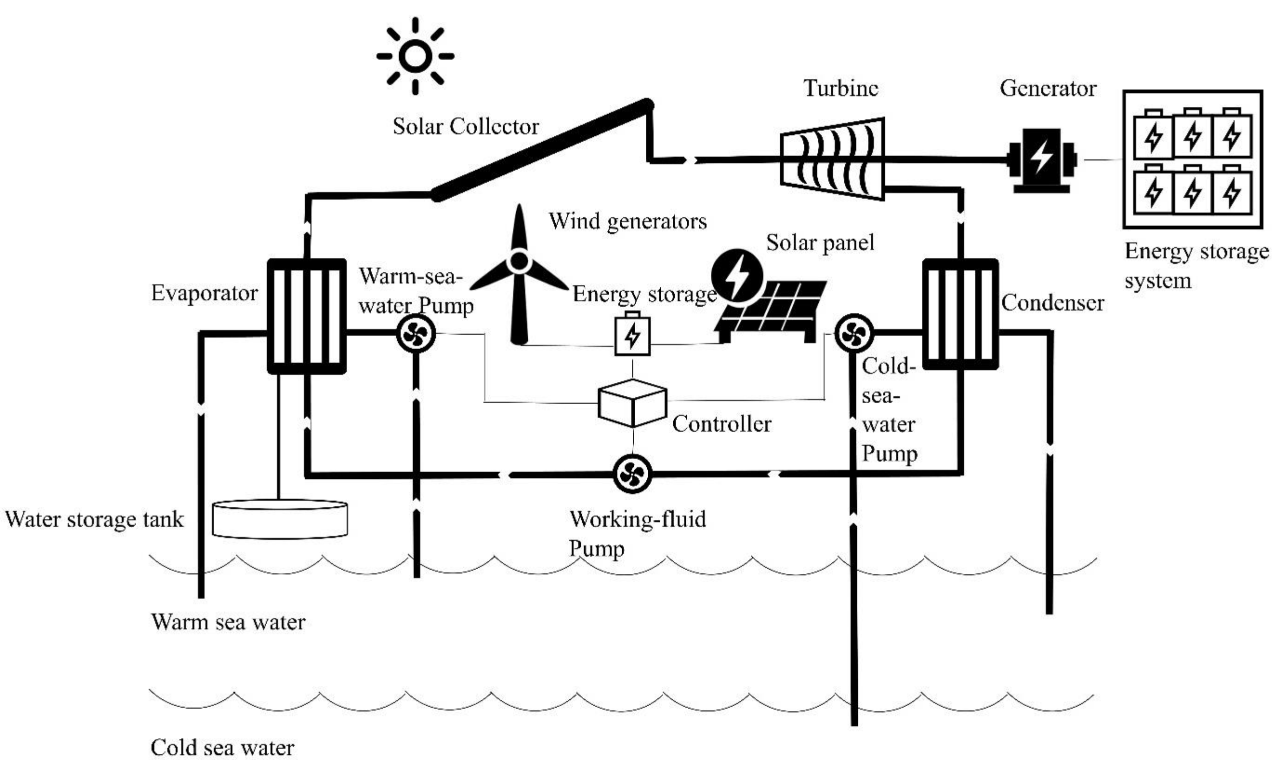

Fig. 1. The schematic shows the structural design of various units of the multi-energy integrated power generation system.

warm water pump, the cold-water pump and the working fluid pump [**27**]. The other part is stored in the energy storage battery. The warm water pump works to extract seawater at 30°C on the ocean surface (set in the South China Sea in this paper) into the evaporator, which is used to preheat the flowing working fluid and discharge it back to the ocean. The working fluid at low boiling point heats up and begins to boil after preheating. The boiling gas is re-heated through the trough solar concentrator and heated to 70°C and become high temperature and high-pressure gas. The high temperature and high-pressure gas enters the turbine to promote its work and drive the turbine generator to generate electricity. After the high-temperature and high-pressure gas is cooled and depressurized, it will be condensed into liquid through the cold seawater condensation system into the working fluid storage tank, and then pumped into the evaporator under pressure by the working fluid pump to form a circulation system. In the cold seawater condensation system, the cold seawater (in this paper, the cold seawater is set at 5°C and 800m deep) is pumped from the cold-water pipe to the condenser in the power generation system. After the work is done, the working fluid enters the condenser and is cooled by cold seawater. The step-down steam in the condenser is processed into liquid water after condensing into liquid water, which is directly passed through the fresh water pipe into the fresh water storage tank for other use. The remaining cold seawater can be discharged directly to the corresponding temperature layer.

The design of SOTEC plant

Fig. 2 show the proposed SOTEC operation, respectively; the figure show the general arrangement of the heat exchangers, pumps, piping, turbine generator, and solar collector. The system uses organic working fluid with low boiling point as cycle fluid and solar energy and surface seawater as the heat source to build a SOTEC plant. The combination of solar energy and OTEC can realize the comprehensive utilization of energy. The working fluid is preheated by warm seawater and then heated by a solar collector which collects solar radiant energy. The working fluid temperature is further increased at the turbine inlet. Trough solar collector is mature and reliable and can raise the temperature of the heat source to more than 100°C. Thus, the circulation heat efficiency of SOTEC system can be improved theoretically, and the practicality of OTEC can be improved. In the SOTEC system circulation process, warm seawater is first used as the preheating source to preheat the organic working fluid. After the heat transfer between surface warm seawater and circulating working fluid is realized in the evaporator, it is sent to the solar collector to further heat the steam temperature, and the steam drives the turbine to expand and do work. After the expansion, the organic working fluid exhaust gas is sent to the condenser to condense and liquefy, and then continues to be circulated by the working-fluid pump for power generation.

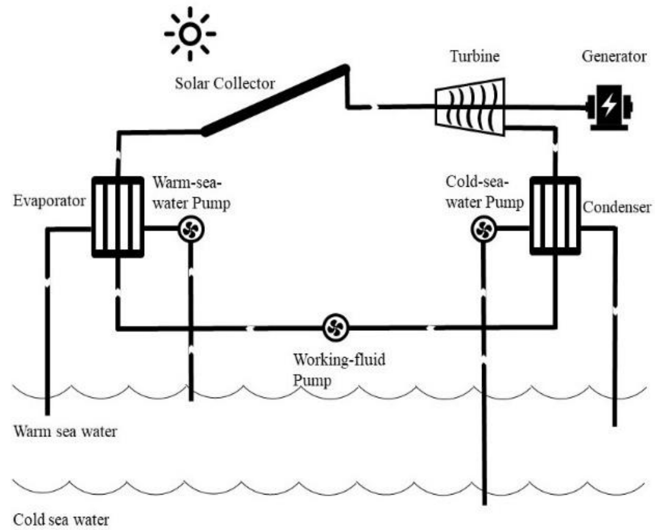

Fig. 2. Schematics of SOTEC operation

Wind-solar complementary system

The SOTEC system requires additional power to the pump when started. After the pump starts working, the SOTEC system enters normal operation. Since SOTEC is generally located by the sea or offshore, solar and wind energy resources are abundant. So, we designed the wind-solar power generation unit to be added to the system, supplemented by energy storage batteries. In order to achieve the SOTEC system energy all self-sufficiency, increase the power output ratio of the whole ocean energy integrated power generation system. General wind turbines and solar panels generate electricity and store it in the battery, which is then distributed by the controller according to demand to warm sea water pumps, deep-sea water pumps and working fluid pumps. Solar cells have monocrystalline silicon, polycrystalline silicon, thin film, perovskite and other types. Perovskite solar cells are up to 30% more efficient than other types.18 PSC's service life has been extended by about one year, and scientists' cooperative exploration of the perovskite solar cell has enabled it to exceed its service life of one year in just a few years. Perovskite is clearly the fastest growing solar technology to date [**27**]. Therefore, it is more helpful for the power supply of the pump when the light is not enough. Universal wind blade is the first choice in the wind power generation system as the generation blade, which is a generation mode involving energy conservation and emission reduction. Now, wind turbines are mainly designed and developed for the sites with large and stable perennial wind speed. The starting wind speed and working wind speed required by wind turbines are both relatively high, so the application area will be limited and wind energy with low speed cannot be fully utilized. For the universal wind driven motor, its wind power can work normally at level 3 or so. Therefore, it is more helpful to pump the power supply when the wind is weak.

Results and discussion

In this paper, the working conditions and parameters of the system are assumed according to the actual situation by referring to the relevant data of OTEC. Then the efficiency of SOTEC system, system power output and seawater desalination capacity are analyzed and calculated.

System operating condition selection

First of all, the South China Sea where the average light intensity was 692.5 w/m^2 [**28**], the average wind speed was up to level 5, and the average wind power density was between (146.721 ~ 695.312) W/m^2 was selected as the project research site. Ammonia is selected as the working fluid for OTEC system [**29**]. Ammonia has good thermal performance and low price. According to the actual situation of the South China Sea and the working evaporation and condensation temperatures of the system, the temperature of seawater in each link of the system is assumed. As shown in **Table 1** at below.

Table 1. Seawater thermometer for each link.

Technical parameters	Temperature T/°C
Cold sea temperature	5
Warm sea temperature	30
Cold seawater rise in temperature	4
The hot sea drops in temperature	4
Evaporator inlet temperature	30
Evaporator outlet temperature	26
Condenser inlet temperature	5
Condenser outlet temperature	9

The SOTEC system is the core of the integrated ocean energy integrated power generation system. Both the warm water supply system and the cold-water supply system are determined by the generation capacity. Therefore, the energy supply and consumption of the whole ocean energy integrated power generation system are determined based on the SOTEC system.

Power systems computation

The system is designed as a megawatt power generation system, in which the SOTEC generate 1MW.

- ***Calculation of SOTEC system***

The SOTEC system is generated by Rankine cycle. **Fig. 3** is the T-S diagram of the system cycle.

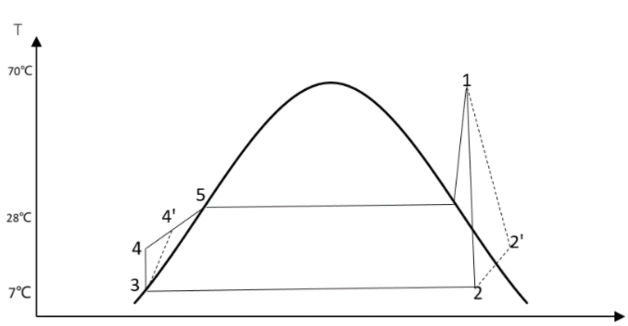

Fig. 3. Ammonia refrigerating cycle system T-S diagram.

Temperature, pressure, enthalpy and entropy at 1, 5 and 3 points can be obtained from the physical properties of ammonia. 2 and 4 points parameters can be obtained from the thermodynamic formula. The data is shown in **Table 2** below:

Table 2. Main parameters of ammonia working fluid cycle.

Serial number	Temperature T/°C	Pressure P/kPa	Enthalpy h/KJ/kg	Entropy s/KJ/(kg.K)
1	70	3312	1464.4	4.553
5	28	1100.7	332.1	1.456
3	7	555	232.5	1.116
2	7	-	1196.799	4.553
4	7.05	-	232.704	1.116

Thermodynamic analysis of the circulation system was carried out according to the data in **Fig. 3** and **Table 2:** the output power of the generator was set at 1MW.
Actual output power of the turbine:

$$P = M_i \times (H_1 - H_2)\eta_f \times \eta_t \quad (1a)$$

$$M_i = 5.19kg/s \quad (1b)$$

Turbine output power:

$$P_t = M_i(H_1 - H_2) = 1388.89kW \quad (2)$$

P is the actual output power of the generator. M_i is the flow rate of working fluid. H_1 is the specific enthalpy of working fluid at turbine inlet. H2 is the specific enthalpy of working fluid at the outlet of turbine. The η_f is the generator efficiency and value of 0.9. The η_t is turbine efficiency and value of 0.8. P_t is the output power of turbine.
Heat released by working fluid:

$$Q_c = M_i(H_2 - H_3) = 5004.71kW \quad (3)$$

Qc is the heat released by working fluid, H3 is the specific enthalpy of the condenser outlet working fluid.
Working fluid pump power:

$$P_g = M_i(H_4 - H_3) = 1.06kW \quad (4)$$

P_g is the actual power consumed by the pump. H_4 is the enthalpy of working fluid at the outlet of working fluid pump.
The heat absorbed by the working fluid:

$$Q_e = M_i(H_1 - H_4) = 6392.50kW \quad (5)$$

Q_e is the heat absorbed by the working fluid.
Heat absorbed by working fluid from warm seawater:

$$Q_{we} = M_i(H_5 - H_4) = 512.88kW \quad (6)$$

Q_{we} is the heat of absorbing warm sea water for the working fluid.
Solar energy absorbed by working fluid:

$$Q_{te} = M_i(H_1 - H_5) = 5842.67kW \quad (7)$$

Q_{te} is the heat of absorbing solar energy for the working fluid.
The warm flow calculation:

$$M_{hs} = \frac{Q_{we}}{C_w \eta_{hr}(T_{wr} - T_{wc})} = 51.25kg/s \quad (8)$$

M_{hs} is the flow of warm seawater. C_w is the heat capacity of warm seawater, with a value of 4.17kJ/(kg·°C). η_{hr} is the hr preheater in thermal efficiency. T_{wr} is the inlet temperature of warm seawater. T_{wc} is the outlet temperature of warm seawater.

Cold water flow calculation:

$$M_{hc} = \frac{Q_c}{c\eta_l(T_{cr}-T_{cc})} = 495.67kg/s \quad (9)$$

M_{hc} is the flow of cold seawater. C is the heat content of condensate, with a value of 4.207 kJ/(kg·°C). η_l is the heat exchange efficiency of the condenser. Tcr is the outlet temperature of cold seawater. Tcc is the outlet temperature of cold seawater.

Warm-sea-water pump power:

$$P_w = \frac{V_w g h_w}{1000\eta_w} = 6.70kW \quad (10)$$

V_w is the warm-sea-water flow, h_w is the warm-sea-water pump head, η is the warm-sea-water pump efficiency, The general value is 0.6, g is the gravity, $g = 9.8\,{}^{m}/{}_{s^2}$.

The warm-sea-water pump has small pressure requirement. Therefore, there is not much requirement for pump head. In the calculation of this paper, the pump with 8m head is assumed to have a 25% loss. The supporting motor power consumption P_{wm} calculation formula is:

$$P_{wm} = P_w \times 1.25 = 8.37kW \quad (11)$$

Cold-sea-water pump power:

$$P_c = \frac{V_c g h_c}{1000\eta_c} = 121.44kW \quad (12)$$

V_c is the cold-sea-water flow, h_c is the cold-sea-water pump head, η is the cold-sea-water pump efficiency, The general value is 0.6, g is the gravity, $g = 9.8\,{}^{m}/{}_{s^2}$.

The cold-sea-water pump has small pressure requirement. Therefore, there is not much requirement for pump head. But the cold water pumped by the pump is deeper. In the calculation of this paper, the pump with 15m head is assumed to have a 25% loss. The supporting motor power consumption P_{cm} calculation formula is:

$$P_{cm} = P_c \times 1.25 = 151.80kW \quad (13)$$

In order to ensure the power requirements of the pump supply system, 162kW wind-solar complementary power generation equipment and corresponding energy storage equipment should be equipped to supply energy for the pump, so as to achieve all self-sufficient energy of SOTEC system.

Thermal efficiency of the system:

$$\eta = \frac{P_j}{Q_e} = \frac{P-P_g-P_{wm}-P_{cm}}{Q_{we}+Q_{te}} = 0.1312 = 13.12\% \quad (14)$$

P_j is the net output power of the turbine. P_g is the actual power consumed by the pump. P_{wm} is the power of the motor with the warm sea water pump. P_{cm} is the power of the motor with the cold sea water pump. Q_e is the heat absorbed by the working fluid. Q_{we} is the heat of absorbing warm sea water for the working fluid. Q_{te} is the heat of absorbing solar energy for the working fluid.

- ***Energy storage system calculation***

The parameters of the battery include voltage and capacity. The nominal voltage of the battery set is 400V, the battery attenuation rate is 0.85, and the deep discharge rate is 0.8. The island residents and the system use 300kWh every day, and it can be used for 3 days. Therefore, the storage battery capacity is required:

$$BC = \frac{300\times3}{0.85\times0.8\times400} = 3308\text{Ah} \quad (15)$$

- ***Freshwater system***

The warm sea water is changed into steam in the flash evaporator, and the working fluid is heated. After the heating, the steam goes into the condenser and liquefies into fresh water, which goes into the fresh water tank from the fresh water pipe. The system gets fresh water while generating electricity. Flash temperature seawater vapor amount M_f can be obtained by formula (16).

$$M_f = {}^{Q_e}/{}_{\gamma} \quad (16)$$

Q_e is the heat absorbed by the working fluid. ɤ is latent heat of vaporization. A reasonable assumption is made here that the outlet temperature of seawater at the evaporator is selected to be 30°C. Looking up the table, the latent heat value of vaporization at 30°C is $\gamma = 2429.7\,kJ/kg$. Substituting into formula (16), the flash warm sea water vapor quantity is 2.63 *t / h*. Since the flash warm sea water vapor is finally converted into fresh water, the fresh water yield is 2.63 *t / h*.

According to the above calculation, the main loads and products of the whole ocean energy integrated power generation system are shown in **Table 3**. it can be seen from the table that most of the output power of the system comes from SOTEC, and the output power is 1000kW. The system needs to be equipped with a 162kW wind-solar complementary power generation device to supply power to the pump in the power generation system. The wind-solar complementary power generation device equipped with the system is mainly used as an auxiliary power source to improve the efficiency of the OTEC system. In addition to the power output, the system can also produce 64T of fresh water every day.

Table 3. Product and energy consumption of comprehensive ocean thermal energy conversion system.

SOTEC system				Wind-solar storage complementary system	Energy storage system	Freshwater system
warm-sea-water pump	cold-sea-water pump power/kW	working- fluid pump power/kW	output power/kW	Wind-solar complementary system power/kW	Storage battery capacity/A.h	Fresh water production/t.d-1
8.37	151.8	1.08	1000	162	3308	64

Further analysis

- On multi-energy complementary OTEC

Based on the SOTEC system, the system combines photovoltaic power generation, wind power generation and energy storage system to form a clean and efficient, stable power generation integrated power generation system. Give full play to their respective advantages in coordination and improve the overall power output ratio of the system. In this paper, the overall power output ratio of the system is defined as the ratio of total output power and total production power. Specifically, the system has the following advantages:

1. The traditional OTEC system is inefficient, generally 1% to 2% [**30**], the SOTEC system uses solar complementary heating, without consuming energy of the system itself, it's efficiency to 13.12%.
2. This multi-energy complementary integrated power generation system, based on the ocean temperature difference energy, the use of landscape complementary power generation, and equipped with energy storage system, the comprehensive use of marine resources. It can be widely used in coastal areas or marine temperature-rich areas such as islands, providing clean and stable electricity for coastal or island residents and deep-sea engineering.
3. The pump work of the power generation supply system of the scenic complementary power generation system does not need the external energy to be imported and self-sufficient. In comparison to the traditional OTEC system, the energy storage device can ensure that the whole system is working continuously. When the light is not the brightest conditions such as in the evening or in winter, the SOTEC system can still be carried out normally.

A final remark is that OTEC system can be used that serves as an energy block chain supply node and that provides users with stable electricity output. An OTEC system can improve its energy conversion efficiency in order to fully utilize ocean resources [**31**].

Conclusion

In this paper, the authors have designed a multi-energy system based on ocean thermal energy conversion. There are still many directions for further study of OTEC. The energy of the pump can be provided by a variety of ocean energy, such as wave energy and ocean current energy. Thus, the challenges of excessive power consumption of the OTEC system can be reduced. A heat-storage station is added to store seawater heated by solar energy during the day and for use at night; the multi-energy system is to generate electricity with high efficiency and stability. The multi-energy system complementary can improve the overall efficiency of the utilization of the ocean resource.

This research proposes a multi-energy complementary integrated power generation system based on SOTEC system. Based on the principles of energy conversion, the SOTEC system is equipped with solar energy, wind energy and other renewable energy power generation devices and energy storage system to improve the overall electric energy output ratio and stability of the system. In order to improve the overall efficiency of the integrated power generation system, perovskite solar cells, universal wind turbines, and ocean thermal energy conversion system supplemented by solar heating were adopted, and the overall efficiency of the system was 13.12%. This research provides an optimized design studies for a high output power system that is an integrated multi-energy system based on the ocean thermal energy conversion. Authors have explored the feasibility of the system integration with power from wind, solar, SOTEC, along with the energy storage and energy management. Based on a specific model, the energy conversion coefficient is provided and shed some light of the competitive distributed power generation in terms of efficiency, stability, and output level.

Finally, as it is shown through the previous theoretical analysis and computer modeling, this research enables the feasibility demonstration of a hybrid energy system, provides tools for the design with various necessary parameters to the engineering specification, and obtains valuable insights for the construction of the real OTEC system.

Keywords

Ocean thermal energy conversion, multiple energy complementarity, solar complementary heat, Rankine-cycle OTEC.

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References

1. Song, Y.; *Journal of Marine Science and Technology*, **2019**, *24*, 466.
2. Khan, N.; Kalair, A.; Abas, N; Haider, A.; *Renewable & Sustainable Energy Reviews*, **2017**, *72*, 590.
3. Moan, T.; Keynote Speech: Engineering for a Future Safe, Economical and Sustainable Use of the Oceans [R]; the sixth international conference on ocean engineering, Ningbo, China **2019**, 11, 3.
4. Cheng, Z.; Svangstu, T.; Moan, T.; *Ocean Engineering*, **2019**, 191.
5. Georges, Claude; *Revue Scientifique*, **1931**, 161.
6. Karottki, G.D.; Spilak, M.P.; Frederiksen, M.; *International Journal of Environmental Research And Public Health*, **2015**, *12*, 1667.
7. Waid, R.L.; The MINI-OTEC test.IEEE, **1979**, 6, 548.
8. Saris, E.; Scholten, W.; Kerner, D.; Overview of International Ocean Energy Activities, HI. Proc Int. Conf. Oc Energy Recovery, Honolulu: HI, **1989**.
9. Alexander, D.; Lockheed signs deal to design largest ocean thermal electric plant [EB/OL], **2013**, 10, 31. https://www.reuters.com/article/us-usa-energy-oceans/lockheed-signs-deal-to-design-largest-ocean-thermal-electric-plant-idUSBRE99T18Z20131030
10. Setiawan, I.R.; Purnama, I.; Halim, A.; *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, **2017**, *8*, 33.
11. Lockheed Martin awarded another $4.4M for OTEC work in Hawaii[EB/OL].**2010**.11.22.https://www.bizjournals.com/pacific/news/2010/11/22/lockheed-martin-awarded-another-44m.html
12. Shumkov I.; UK OTEC developer kicks off crowdfunding campaign[EB/OL].**2018**.2.21.https://renewablesnow.com/news/uk-ocean-thermal-energy-developer-kicks-off-crowdfunding-campaign-602232/

13. OTEC news. Funding NEMO: Offshore OTEC project awarded in NER 300 program[EB/OL]. **2017**.7.9. http://www.otecnews.org/2014/07/offshore-otec-project-nemo-awarded-ner-300-funding-program/
14. Makai Ocean Engineering working with Navy on Big Island OTECproject[EB/OL].**2013**.3.19.https://www.bizjournals.com/pacific/news/2013/03/19/makai-ocean-engineering-working-with.html
15. Comfort, C.M.; Vega, L.; Environmental assessment for ocean thermal energy conversion in Hawaii: Available data and a protocol for baseline monitoring,OCEANS **2011**. IEEE, **2011**.
16. Cochran, R.E.; Laskina, O.; Trueblood, J.V.; *Chem*, **2017**, *2*, 655.
17. Cunningham, J.; Magdol, Z.; Kinner, N.; Ocean Thermal Energy Conversion: Assessing Potential Physical, Chemical, and Biological Impacts and Risks,National Oceanic and Atmospheric Administration, **2010**.
18. Zyga, L.; Thermoelectric power plants could offer economically competitive renewable energy PhysOrg[EB/OL].**2014**.12.19. https://phys.org/news/2014-12-thermoelectric-power-economically-competitive-renewable.html
19. Callaghan, J.; Future marine energy-results of the marine Energy Challenge; Cost competitiveness and growth of wave and tidal stream energy. CTC601[R]. London, UK, **2006**.
20. Takahashi, M.; Deep Ocean Water as Our Next Natural Resource[M]. Terra Scientific Publishing Company, Tokyo, Japan. **1991**.
21. Kim, N.J.; Ng, K.C.; Chun, W.; International Communications in Heat and Mass Transfer, **2009**, 36, 1008.
22. Wang, L.; Shi, L.X.; Lu, D.Q.; *Renewable Energy Resources*, **2010**, *28*, 134.
23. Yamada, N.; Hoshi, A.; Ikegami, Y.; *Renewable Energy*, **2008**, *34*, 1752.
24. Yilmaz, F.; *Energy Conversion and Management*, **2019**, *196*, 557.
25. Aydin, H.; Lee, H.S.; Kim, H.J.; Shin, S.K.; Park, K.; *Renewable Energy*, **2014**, *72*, 154.
26. Fuller, R.D.; *Ocean Management*, **1978**, *4*, 241.
27. Li, Z.;Chee K.W.Z.; Yang, Z.; Su, J.; Zhao, J.; Jin, A.J.; *Advanced Materials Letters*, **2020**, *11*, 20051505.
28. Khan, M. R. B.; Jidin, R.; Pasupuleti, J.; Data in Brief, **2016**, 6, 117.
29. Yoon, J.I.; Son, C.H.; Baek, S.M.; *Applied Thermal Engineering*, **2014**, *72*, 304.
30. Heydt, G.T.; *Proceedings of the IEEE*, **1993**, *81*, 409.
31. Li, Z.; Su, J.; Jin, A.J.; *Adv. Mater. Lett.*, **2021**, *12*, 3.

Authors biography

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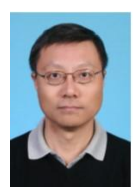

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Graphic abstract

Ocean energy utilization can be utilized. there is enormous energy in the ocean. For example, the ocean thermal energy conversion (OTEC) can generate the electric energy driven by temperature differentials between the surface seawater and the deep seawater. Moreover, a multi-energy complementary energy system based on OTEC stability can integrate solar energy, wind energy, energy storage and OTEC energy. In this article, the basic principle and working process of the approach are studied; the system efficiency is calculated. The complementary system of OTEC can improve the ratio of power generation output efficiency and output power stability. The differential temperature of the work medium can be increased with solar heating, so called SOTEC, so that the efficiency of the complementary OTEC system can be improved and reach 13%.