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Thermodynamic Evaluation of a hybrid solar concentrating photovoltaic/Kalina cycle for full spectrum utilization

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Abstract

Current trends in energy supply and use are unsustainable, concentrating photovoltaics (CPV) would realize the cost-competent photovoltaic application in future, however, its low-temperature waste heat is commonly to heat or refrigerate. From the view of reducing the condensation pressure of Kalina cycle, a hybrid solar concentrating photovoltaic/concentrating solar power (CPV/CSP) system is proposed in this paper and has been capable of converting low-temperature waste heat (65℃) from solar cells into electricity with the exergy efficiency of 26.5%. Meanwhile, the simulation results point out that hybrid system can raise the solar-to-electricity efficiency of solar cells by approximate 2.4 percent points by heat recovery, leading to a feasible strategy for the decrease in costs of solar energy utilization.

Keywords: concentrating photovoltaic; concentrating solar power; Kalina cycle; solar energy utilization.

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1. Introduction

According to global status report [1], the renewable power capacity in place was enough to supply an approximate 23.7% of global electricity by the end of 2015. The solar energy, solar photovoltaics (PV) and concentrating solar power (CSP), accounted for 30% of the total renewable capacity (not including hydro). The total global capacity of solar PV and CSP had reached 227 GW and 4.8 GW, respectively. It was worth noting that CSP system can convert

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the full-spectrum solar energy into heat, however, PV system can commonly convert visible portion of the solar spectrum into electricity, and the unused ultraviolet and infrared portion was wasted as heat.

In fact, the concentrating photovoltaics provided a cost-competitive technology for large-scale solar PV, however, the temperature of cells should been controlled in the range of low-temperature for effective solar-to-electricity conversion. For further using waste heat energy to increase the solar energy utilization, some researchers had proposed some concepts based on line focus concentration system. For example, A. Al-Alili et al. [2] proposed a high efficiency solar air conditioner using concentrating photovoltaic/thermal collectors, in which the approximate 80 ºC waste heat from solar cells driven a solid desiccant wheel cycle in air condition and a COP of 0.68 is obtained that higher than other solar conditioner patterns. Joe S. Coventry [3] designed and fabricated a concentrating photovoltaic/thermal solar collector, and the measured results shown that the test bench can recover 58% low-temperature waste heat from solar cells to domestic hot water. The low-temperature characteristic of waste heat from solar cells decided its common utilization of heating or refrigerating rather than powering.

For low-medium temperature CSP, especially the parabolic trough collector technology, Kalina cycle provided a promising approach for converting solar heat into power. [4] However, the output pressure of turbine in Kalina cycle was higher than that in steam Rankine cycle due to the requirement of condensation pressure in condenser. It meant that the exhaust ammonia water vapor of turbine had an ability to further expand and produce work if the condensation pressure was decreased by using lower-temperature coolant rather than ambient water. In fact, for further cooling ammonia water basic liquid in condenser, using electricity to refrigerate was uneconomical. Thus, integrated absorption refrigerator driven by low-grade waste heat with solar Kalina cycle was a competent method.

In this paper, a hybrid system for full spectrum utilization is proposed. In the hybrid system, the concentrating solar cells are cooled and then obtain low operation temperature which can achieve highly effective conversion of solar to electricity. Meanwhile, low-temperature heat from solar concentrating photovoltaic system is used to drive LiBr absorption refrigerator and the refrigerant further cools the ammonia water out from the condenser in Kalina cycle. In this case, condensation pressure of basic ammonia water liquid can be reduced and then the turbine would output more work.

2. System description

2.1 Concentrating solar power system with parabolic trough collector

Figure 1 shows the flow diagram of solar-driven Kalina cycle, it is comprise of concentration subsystem with parabolic trough collector and Kalina cycle subsystem. In the concentration system, the Therminol VP-1 oil is used in the parabolic trough collector to collect solar thermal energy, and then the solar thermal energy (370 ºC) released from the oil is transferred to ammonia water in Oil-ammonia exchanger. In the Kalina cycle subsystem [5], the ammonia water is super-heated by the oil in the Oil-ammonia exchanger and expands in turbine to produce work. The route of the working fluid is s16 → s17 → s1 → s2 → s3 → s4 →s5, and the route of the lean liquid from separator is s14 → s15. The working fluid and the lean liquid are mixed to form the basic liquid, which flows by s6 → s7 → s8 → s9. Next, the basic liquid is divided into two flows: one is sent to the separator (s11 → s12), and the other is mixed with the vapor from the separator to form the working fluid.

2.2 Hybrid system with absorption refrigerator

Based on the solar-driven Kalina cycle system with parabolic trough collector, an absorption refrigerator driven by waste heat from concentrating photovoltaic subsystem is layout after condenser 1 to further cool the basic liquid. For this reason, the output pressure of turbine can be reduced and then the expansion ratio increase in the turbine, bringing about profit of more work. In concentrating photovoltaic subsystem, the direct normal irradiation is concentrated by parabolic trough collector to surface of solar cells and the radiation within the spectral response of PV cells is converted to electricity. It is worth noting that the concentrating photovoltaic subsystem has the following two primary advantages: 1) the solar-to-electricity efficiency of solar cells can be effectively improved and 2) the waste heat recovery of solar cells can be centrally collected. Meanwhile, it is necessary to consider the effect of temperature on the solar-to-electricity conversion of solar cells. Thus, in this paper, using the Therminol