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Performance study of solar cell arrays based on a Trough Concentrating Photovoltaic/Thermal system

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ABSTRACT

The performances of solar cell arrays based on a Trough Concentrating Photovoltaic/Thermal (TCPV/T) system have been studied via both experiment and theoretical calculation. The *I–V* characteristics of the solar cell arrays and the output performances of the TCPV/T system demonstrated that among the investigated four types of solar cell arrays, the triple junction GaAs cells possessed good performance characteristics and the polysilicon cells exhibited poor performance characteristics under concentrating conditions. The optimum concentration ratios for the single crystalline silicon cell, the Super cells and the GaAs cells were also studied by experiments. The optimum concentration ratios for the single crystalline silicon cells and Super cells were 4.23 and 8.46 respectively, and the triple junction GaAs cells could work well at higher concentration ratio. Besides, some theoretical calculations and experiments were performed to explore the influences of the series resistances and the working temperature. When the series resistances R_s changed from 0 Ω to 1 Ω, the maximum power P_m of the single crystalline silicon, the polycrystalline silicon, the Super cell and the GaAs cell arrays decreased by 67.78%, 74.93%, 77.30% and 58.07% respectively. When the cell temperature increased by 1 K, the short circuit current of the four types of solar cell arrays decreased by 0.11818 A, 0.05364 A, 0.01387 A and 0.00215 A respectively. The research results demonstrated that the output performance of the solar cell arrays with lower series resistance was better and the working temperature had a negative impact on the current under concentration. In addition, solar irradiation intensity had certain effects on the solar cell's performance. For the crystalline silicon solar cell arrays, when the solar direct radiation exceeded a certain value, the *I–V* curves almost became a straight line and the output performances decreased due to the high series resistance leading to the high power loss. For the triple junction GaAs solar cell array, its performance was always excellent.

1. Introduction

Photovoltaic power has been applied in a wide variety of specialized applications including space, remote communication, and has successfully occupied an irreplaceable position [1,2]. However, the cost of photovoltaic is so high that it can not compete on a cost effective basis with traditional power generation. By concentrating the sun's radiation through magnification, the intensity of solar radiation may be increased to between several times and several hundred times its standard output. This resulting increase in power output yields a decreased cost. A CPV/T (concentrating photovoltaic/thermal) system is a hybrid photovoltaic and thermal power generation system. The solar cell is the key component that determines the performance of a CPV/T system. Systems with different concentration ratios should adopt different solar cells to improve systems' performance.

In 2004, the Renewable Research Institute of Australia National University performed a detailed study on a Trough Concentrating Photovoltaic/Thermal (TCPV/T) system. The efficiency of the solar cell array reached 22% and the cost of electricity generation was reduced by 40% compared with the traditional PV system [3–5]. Much work has previously been done on designing the concentrating collector as well as developing new solar cells [6–8]. Mittelman [9] investigated the performances and cost of *s* CPVT system with single effect absorption cooling in detail. Kribus [10] presented the evaluation and design of the miniature concentrating PV (MCPV) approach, and analyzed the heat transport system, the electric and thermal performance, the manufacturing cost, and the resulting cost of energy. Zhai [11] proposed a hybrid solar heating, cooling and power generation system based on screw expander and silica gel–water absorption chiller, and analyzed the energy, exergy and cost. Chow [12] gave a review of the developing trend of the PVT technology, in particular the advancements in recent years and the future work required. Wu [13] proposed a parabolic dish/AMTEC (alkali metal thermal to electric converter)

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Nomenclature

I	current (A)	R_{sh}	shunt resistance of cell (Ω)
M	photovoltaic conversion factor (m^2/V)	I_{sc}	short circuit current (A)
ϕ	radiation intensity (W/m^2)	V_{oc}	open circuit voltage (V)
I_0	p–n junction reverse saturation current (A)	P_m	maximum power of cell array (W)
Q	electric charge constant (1.6×10^{-19} °C)	I_m	the current of the maximum power point (A)
V	voltage (V)	V_m	the voltage of the maximum power point (V)
R_s	series resistance of cell (Ω)	V_w	wind velocity (m/s)
A	diode quality factor	V_f	flow rate (L/h)
K	Boltzmann constant (1.38×10^{-23} J/K)		
T	temperature of solar cell (K)		

solar thermal power system, and the overall conversion efficiency could reach up to 20.6% with a power output of 18.54 kW. Singh [14] studied and compared the thermal performances of the four identical trapezoidal cavity absorbers for linear Fresnel reflecting solar device. A parabolic solar cooker with automatic two axes sun tracking system was designed, constructed, operated and tested by Mohammed [15], Wu [16] researched the thermal and power characteristics of solar cells in concentration, Yuan [17] investigated the increased performance from utilizing a solar booster on a conventional silicon cell.

Our research group began to investigate the TCPV/T system in 2005. The performances analysis of the TCPV/T system were reported in [18,19]. But the characteristic research and performance comparisons of some certain solar cells based on a Trough Concentrating Photovoltaic/Thermal (TCPV/T) system have not been previously reported. For this paper, the trough collector has been constructed, by taking a single crystalline silicon solar cell array, a polysilicon solar cell array, a Super cell array and a triple junction GaAs cell array as test arrays. Several experiments and theoretical calculations have been carried out based on the Trough Concentrating PV/T system. All those works are beneficial to the further study on optimizing the Trough Concentrating system and offer practical value to the design of a large scale concentrating PV/T power generation.

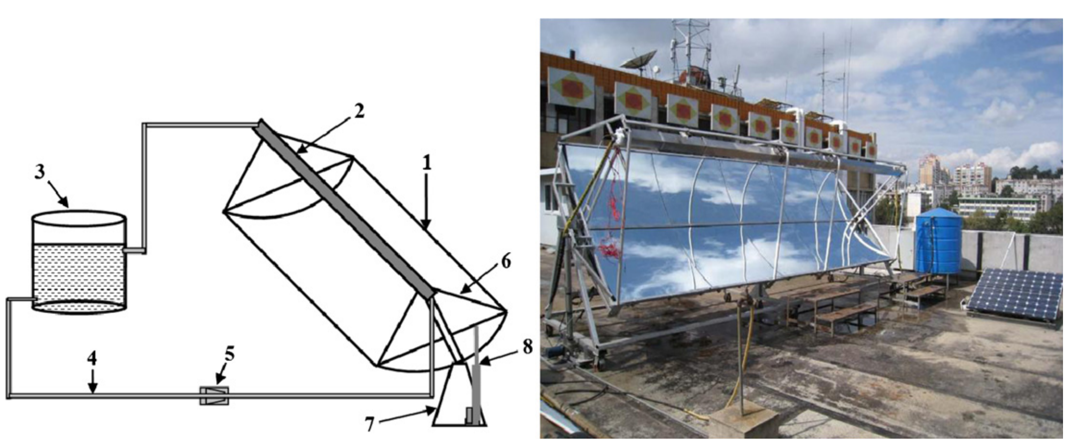
2. The Trough Concentrating Photovoltaic/Thermal system

Fig. 1 shows the sketch and photograph of a TCPV/T system which can generate electricity and heat and consists of a trough reflecting mirror, a light-concentrating receiver, a sun tracking system, an electrical energy output system and a thermal energy storage system. The solar cell arrays are pasted on the lighting plate of the receiver to produce electric power when the sun light is concentrated on them. Then, the heat carrier fluid (water) is pumped into the inner cavity and flows through the absorber channel horizontally to transfer thermal energy and thereby reduce the temperature of the cells. Concurrently, the thermal energy in the water is stored in a water tank as hot water. A fin structure is added in the cavity to enhance the heat transfer from the absorbing surface to heat the carrier fluid. The back and sides of the receiver are insulated with 10 mm thick glass–wool and encased by a sheet aluminium cover. The solar energy accepted by the system will be converted into electricity via solar cell arrays and thermal energy and through heat conduction by plate. In order to collect the direct radiation, the solar concentrators are required to track the sun. The system tracks the solar altitude angle by adjusting the push rod in single-axis east–west tracking mode (Trough Concentrator north–south oriented).

The system has a geometric concentration ratio of 31 while the energy flux concentration ratio is 20 as tested via a laser power instrument (MODEL 460–1A from EG&G GAMMA SCIENTIFIC SANDIEGO CALIFORNIA). The aperture area of mirror is 10 m^2 while the valid concentrating area is 9.25 m^2.

3. Experimental setup and theoretical basis

The TCPV/T system was tested experimentally to determine its photovoltaic performance. Four types of solar cells, a single



1. Trough Concentrator 2. Receiver 3. Storage tank 4. Pipe

5. Pump 6. Connecting rod 7. Supporter 8. Push rod.

Fig. 1. The sketch and photograph of Trough Concentrating PV/T system.