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Transient Model of Hybrid Concentrated Photovoltaic with Thermoelectric Generator

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Abstract

Transient performance of a concentrated photovoltaic thermoelectric (CPV-TEG) hybrid system is modeled and investigated. A heat sink with water, as the working fluid has been implemented as the cold reservoir of the hybrid system to harvest the heat loss from CPV cell and to increase the efficiency and performance of the hybrid module. This investigation is carried out by using a numerical simulation approach with MATLAB software. The governing equations for CPV-TEG hybrid system in transient state is derived and discretized. The results are consisting of the variation of the temperatures, power generation and efficiency of the CPV and TEG with the time in the transient condition.

Keywords: Concentrated Photovoltaic Cell; Thermoelectric Generator; Hybrid Syestem; Solar Energy; Transient Model.

1. Introduction

The use of solar energy is an important method to reduce the global greenhouse crisis. Due to better utilization of this source of energy it is important to improve the efficiency of photovoltaic (PV) cell. Even while using high efficiency concentrating multi junction (CMJ) cells, more than half of the solar irradiance is not converted into electricity and is dissipated by heat. Harvesting of this heat for increasing the system’s efficiency even more can be

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approached by applying thermoelectric devices. CPV-TE hybrid system could be a prospective way to improve the utilization efficiency of solar energy. Several researches have been carried out focusing on improving efficiency of the hybrid CPV–TE [1-4]. Due to the variation of weather condition, considering transient model in heat transfer is very useful and applicable. A TE module was placed thermally in series with a photovoltaic module by Dallan et al. [5]. It was shown that the PV module's power output within the configuration of the PV–TE hybrid system increases up to 39% under fixed thermal input conditions relative to the PV module's operation in absence of the TEM. Beeri et al. [6] have investigated a CPV–TE hybrid demonstrator experimentally and theoretically. They found that, including Peltier cooling effect, the total contribution of the TEG to the hybrid system's efficiency reached a value of almost 40% at a sun concentration level of 200. Energy conversion and heat transfer process of the spectrum splitting CPV-TE hybrid system was investigated by Ju et al. [7], and an energy based numerical model for CPV-TE hybrid systems was presented. Results show that in comparison with PV-only systems the spectrum splitting PV-TE hybrid systems are more appropriate for working under high concentration condition. The effects of a series of parameters on the PV-TE hybrid system of solar energy utilization have been analyzed by Zhang et al. [8]. They found that among these parameters, temperature is one of the dominant factors, which affects the conversion efficiency of such hybrid systems. They also found that a large convection heat transfer coefficient is beneficial to maintain a larger temperature gradient of the thermoelectric module. Kraemer et al. [9] presented a general optimization methodology for the hybrid systems consisting of (PV) and (TE) modules. They developed the optimization method for the hybrid systems operating at low temperature combined. A thermally coupled model of PV/TEG panel was presented to accurately calculate performance of the hybrid system under dissimilar weather conditions by Rezania et al [10]. They found that with current thermoelectric materials, the power generation by the TEG is insignificant in comparison with electrical output by the PV panel, and the TEG plays only a small role on power generation in the hybrid PV/TEG panel. The possibility of using of thermoelectric generators in solar hybrid systems has been investigated by Urbiola et al. [11]. It was found that the TEG's efficiency had almost linear dependence on the temperature difference ΔT between its plates, reaching 4% at $\Delta T = 155^{o}C$ (hot plate at $200^{o}C$) with 3W of power generated over the matched load. A thermodynamic model for analyzing the performance of a (CPV–TEG) hybrid system including Thomson effect in conjunction with Seebeck, Joule and Fourier heat conduction effects was developed by Lamba and Kaushik [12]. It was observed that by considering Thomson effect in TEG module, the power output of the PV, TE and hybrid PV–TEG systems decreases and at C = 1 and 5, it reduces the power output of hybrid system by 0.7% and 4.78% respectively.

According to previous investigations in the fields CPV-TEG hybrid systems, it can be found that hybrid systems are more efficient for harnessing solar energy. Hybrid systems could be optimized in different ways and also different combinations are exists. Due to variation of weather condition during a day for example in cloudy days, power generation and efficiency of hybrid system will changed with the time. Considering this variation can be very important and practical. The aim of this paper is the investigation of thermal behavior, power generation and also efficiency of CPV-TEG hybrid system in the transient condition for different solar radiations. Therefore, we propose a numerical model with considering some logical simplifying assumptions.

2. Numerical model

Fig.1 illustrates physical model of the CPV-TEG system including the heat sink. In order to verify the effect of the new TEG system with CPV cells, a corresponding numerical model algorithm is established. An unsteady-state heat transfer model with applicable simplifications is used to study the performance of the hybrid system. The main simplifying assumptions are as follows:

- The CPV and TEG modules are insulated thermally, therefor, thermal leakage from the modules to the surroundings is assumed to be zero except the hot surface of the CPV cell and heat dissipation from bottom surfaces of the cells, where are specified as heat source and heat sink, respectively.