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Applications of hybrid photovoltaic modules with thermoelectric cooling

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Abstract

Among the energy sources with low efficiency, thermoelectric systems are used for hybrid systems with improved performance. This paper provides a review of recent literature concerning the integration of ThermoElectric Cooling (TEC) devices into PhotoVoltaic (PV) generators to constitute PV-TEC systems. The role of TEC is to reduce the temperature of the PV cells, to increase the efficiency of the system, its power capacity and lifetime. The paper also contains a formulation of thermoelectric module equations referring to cooling capacity, rate of heat rejected to the ambient and input power, together with the electrical model of the PV generator.

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Keywords: Thermoelectric cooling; thermoelectric module; photovoltaic; hybrid system; efficiency; review.

1. Introduction

The current trends concerning High Energy Efficiency and High Renewable energy sources are set up in documents such as the Energy Roadmap 2050 of the European Commission [1], as well as in other sources addressing the promotion of better environmental impact and more green building applications [2].

Among the most effective renewable energy technologies, photovoltaic (PV) systems are emerging because of the possibility of high diffusion in different types of climates, increasing possibility of integration into the building architectures in building-integrated photovoltaic (BIPV) solutions, and widespread experience of design and installations gained by a number of operators in recent years. These characteristics make PV systems a very

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interesting asset in the integration of energy sources in nearly-zero energy buildings (NZEB). In order to further improve the situation, the effectiveness of PV technologies has to make further progress in order to reach, in a systematic way, the grid parity [3-9]. This condition occurs when the price of the self-consumed energy produced by PV is equal to the price of the energy purchased from the electrical grid [10].

In order to become more attractive, the PV systems have to become more and more efficient. For this purpose, the parameters affecting the PV production have to be modified in the direction of enabling higher productivity and efficiency. Among these parameters, the PV cell temperature plays a key role in determining the PV cell efficiency: when the other conditions (e.g., solar irradiance, wind, humidity, etc.) are constant, the higher the temperature, the lower the PV cell production. Hence, one of the techniques used to improve the PV cell efficiency is to insert a cooling system able to reduce the cell temperature during operation. For this purpose, this paper addresses the use of thermoelectric materials, considered to be a viable solution for electrical and thermal energy harvesting, as well as to implement easily controllable solutions to condition the temperature even in small-size applications [11,12].

From the technology viewpoint, a thermoelectric module is a bi-directional device, which operates in two ways:

- as a thermoelectric generator (TEG), exploiting the Seebeck effect, when the module is subject to a temperature difference and generates an output voltage in direct current (DC) [13];
- as a thermoelectric cooler (TEC), exploiting the Peltier effect, when the module is supplied by the electrical system with a DC current and a temperature difference is created between its hot and cold sides [14].

This paper addresses only the TEC devices, providing a review of recent literature concerning the integration of these devices into PV generators to constitute hybrid PV-TEC systems. The TEC devices transfer heat from one zone to another by the utilization of an amount of the electrical energy produced by the PV system. Integrating the TEC device with the PV cells may have two positive consequences:

- enhancement of the *power capacity* of the PV modules, that is, the maximum power output under given operating conditions.
- increase of the *electrical efficiency* of the PV system, including the following causes of losses [15].

In practice, additional input power is necessary for supplying the TEC module. The technical effectiveness of the hybrid PV-TEC solution exists when power and energy output from the system with TEC is higher than power and energy output of the corresponding solution without TEC. Establishing the limit conditions for this effectiveness under different ambient situations is one of the current open fields of research.

The hybrid PV-TEC systems have been studied in a limited way until now, with interesting conversion efficiencies emerging mainly for concentrating photovoltaic (CPV) solutions [16]. However, thermoelectricity from TEG and TEC is a “green technology” and the related solutions are becoming more and more interesting under today’s higher concern on energy conservation and environment protection [2,17].

A TEC has compact construction, limited maintenance needs and long duration of use because of the absence of moving parts, leading to high reliability (over 200,000 life hours), and may operate in any working position. Hybrid PV-TEC systems are good candidates for thermal energy harvesting, reducing the PV modules temperature and improving their efficiency. Meanwhile, the temperature reduction implies the possibility of increasing the power capacity of the PV cells, as the power generated by the PV cells at a given solar irradiance is higher when the temperature is lower.

In recent years, a number of studies appeared in the literature about the incorporation of TEC into the different types of photovoltaic systems mentioned above. The main issues concerning different types of PV systems are:

- *Fixed rooftop PV systems*: the increased temperature of the PV cells can damage the PV modules, reducing both lifetime and energy conversion efficiency [18]. On the operational side, the system is fixed and does not need specific controls.
- *Sun-tracking PV systems*: the temperature reached by the PV cells is higher with respect to fixed ground mounted PV systems, since a sun-tracking system makes the PV cells receive more solar irradiance during time. The system is in motion and its position needs to be controlled.