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Design of a self-adjusted jet impingement system for cooling of photovoltaic cells

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ABSTRACT

This study aims to join up wind and solar energy as the renewable energy sources for more efficient production of electrical energy. A laboratory-scale cooling device based on a conic wind-collecting tunnel was designed and then fabricated to cool down a photovoltaic (PV) cell. The collected wind from conic tunnel was employed with two goals; first, it was considered as a coolant fluid for PV cell. Second, it was applied for producing electrical energy via a designed turbine. The great potential of the proposed cooling device on the performance of the PV cell are the focus of this study. The obtained results reveals that the total output power was increased 36% from both the PV cell and turbine electrical energy production. In order to explain the observed results, a CFD modeling based on MRF technique were undertaken. The flow distributions in two modes (with and without turbine) were compared and the effect of turbine blade was then interpreted in terms of air flow pattern diverted to underneath of the studied PV cell.

1. Introduction

In recent years, renewable energy is extensively advocated by many countries. Among the renewable energy resources, photovoltaic (PV) cells are very attractive, since they supply different forms of energy such as electricity and heat [1]. Generally, solar cells can be broadly classified into two systems; thermal energy system which converts solar energy into thermal energy and photovoltaic energy system which converts solar energy into electrical energy [2]. It is well known that during the operation of the PV cell only around 15% of solar radiation is converted to electricity, and the rest was converted to heat. Thus, the electrical efficiency and output power of the solar cells will decrease, when the operating temperature of the PV module increases. An effective way of improving efficiency and reducing the rate of thermal degradation of a PV module is cooling the PV module during operation [3–8]. Different cooling techniques have been investigated and discussed by many researchers to cool the PV module [9–16]. Concerning the air based systems, Valeh-e-Sheyda et al. [17] enhanced the performance of PV cell in terms of output power up to 46.54%. They utilized a wind-driven roof top turbine ventilator, as cost effective ventilation device, to cool down a PV cell. Besides, Ji et al. [18] constructed a flat-box aluminum alloy photovoltaic and water-heating system. The outdoor performance of their PV/T system demonstrated that a daily electrical efficiency of about 10% were achievable. Absorption and adsorption cooling systems [19], solar cell immersing in the liquid systems [20], zeolite-active carbon adsorbent [21], and liquid jet impingement systems [22–24] were other solar cooling technologies to achieve a breaking through in the integration of solar cooling systems with buildings.

Finally, the micro-channel cooling schemes [25] and the application of gas-liquid two-phase flow in micro-channels [26] estimates 38% increase in maximum output power of PV cell. By comparing the systems, one can note that water-based systems can be better controlled and operated with a low electrical energy input, since water has a higher heat capacity. However, due to the easier construction and operation of air-based PVT, they can be treated as an alternative and cost effective solution, since they are relatively mature technologies [27].

On the other side, integrating renewable sources such as wind and/or solar energy into existing diesel plants can achieve considerable fuel savings. Although PV or wind power systems are far

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Nomenclature

C_μ, $C_{1\varepsilon}$, $C_{2\varepsilon}$	RNG $k-\varepsilon$ model constants
I_m	current at maximum power (A)
p	static pressure (N m^{-2})
P_{Max}	maximum power of photovoltaic arrays (W)
P_1	output power of PV cell after cooling at low flow rate of air (W)
P_2	output power of PV cell after cooling at high flow rate of air (W)
P_{ref}	output power of reference PV cell (W)
V_m	voltage at maximum power (V)
V_{outlet}	wind speed (m s^{-1})

Abbreviations

DC	alternating current
I	average intensity on absorber plate (W m^{-2})
PVT	photovoltaic solar thermal
Q	air flow rate (m^3 h^{-1})

Greek letters

μ	viscosity (kg m^{-1} s^{-1})
v	velocity vector (m s^{-1})
P	density (kg m^{-3})
σ_k, σ_ε	turbulent Prandtl numbers for $k-\varepsilon$
τ	stress tensor (Pa)

from being economic for providing electricity, in comparison to conventional fossil fuel, they are generally used in remote areas where it is highly uneconomical to extend the electrical power grid system [28].

In the present study, a jet impingement laboratory-scale device has been proposed for cooling PV cell. This device, in fact, introduces a new technique to join up solar and wind energy as the renewable energy sources in order to increase the total energy produced. On the next step, the experimental system was developed and the results were discussed for measured values. By varying the air flow rate through the wind collector, the electrical performance was also investigated in PV cell.

In addition, installation effect of a wind turbine inside the cooling chamber was considered on the PV electrical power, as another focus of this study. CFD modeling of the cooling system was also performed to explain the reasons for the observed results. The great potential of the simple cooling jet device as well as the self-steering wind turbine, applied inside device, has been considered as the novelty of this investigation.

2. Experimental procedure

2.1. Experimental set-up

The schematic illustration of fabricated testing setup was portrayed in Fig. 1. According to the figure, the considered hybrid system is a combination of wind and photovoltaic system. A vertical axis board, called "self-steering wind vane", was installed at the top of the air tunnel to determine the wind direction. It is important to notice here that the self-steering wind vane works without electricity, makes no noise and can be repaired on-board. In this case, the height at which the cooling device is placed may play a significant role in easily swinging and accurately showing wind directions. Besides, wind vanes located close to the ground might not provide correct readings. They must be placed at top of buildings, in order to avoid obstructions and get clean gusts of wind.

As the wind hits to the narrow upright tail, it spins at right angles from which the wind is blowing, so that the chamber adjusts itself in direction of wind stream. This direction is quite important for more efficient cooling, as well as to ensure that the turbine can achieve its maximum potential power generation. The wind flows into the inlet chamber with a wall thickness of 1 mm and rounded corners.

A PV module with effective area of 374 cm^2 was connected to an electronic load system for power testing. The PV cell was placed over a steel frame and temperature sensors have been attached on the backside of the module, with an extremely thin layer of a thermal epoxy to measure 6 different points across the entire PV surface. Fig. 2 presents the locations of the thermocouples at the backside of the PV panel.

The main characteristics of the elements applied in the system were given in Table 1. The fabricated solar simulator apparatus consists of metal halide lighting sources, collimated lens with a transmittance of 99%, and a power driver unit for continuous light. Total of three metal halide packages were evenly loaded on aluminum heat sink plate. It is interesting to note that the main idea of

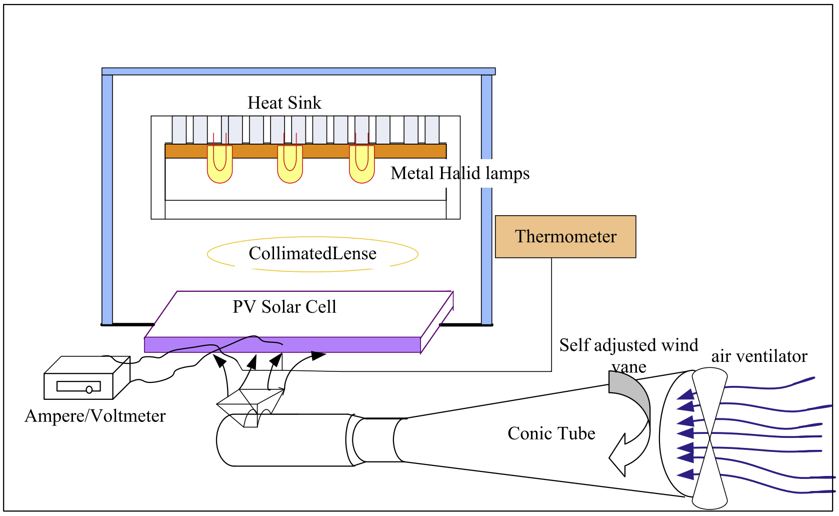

Fig. 1. A schematic diagram of the experimental set-up of the PV.