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Advancements in hybrid photovoltaic systems for enhanced solar cells performance

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ABSTRACT

Photovoltaic (PV) cells can absorb up to 80% of the incident solar radiation available in the solar spectrum, however, only a certain percentage of the absorbed incident energy is converted into electricity depending on the conversion efficiency of the PV cell technology. The remainder of the energy is dissipated as heat accumulating on the surface of the cells causing elevated temperatures. Temperature rise of PV cells is considered as one of the most critical issues influencing their performance, causing serious degradation and shortening the life-time of the cells. Hence cooling of PV modules during operation is essential and must be an integral part of PV systems particularly in sun-drenched locations. Many researches have been conducted investigating a range of methods that can be employed to provide thermal management for PV systems. Among these designs, systems utilizing air, liquid, heat pipes, phase change materials (PCMs), and thermoelectric (TE) devices to aid cooling of PV cells. This paper provides a comprehensive review of various methods reported in the literature and discusses various design and operating parameters influencing the cooling capacity for PV systems leading to an enhanced performance.

Contents

Abbreviations: a-Si, amorphous silicon; BIPV, building integrated photovoltaic; CPC-PVT, compound parabolic concentrating photovoltaic–thermal; CPV, concentrated photovoltaic; c-Si, crystalline silicon; FP-PVT, flat plate photovoltaic–thermal; HTS, high temperature stage; MCPVT, micro-channel photovoltaic–thermal; MCSCT, micro-channel solar cell-thermal; MEPCM, microencapsulated phase change material; PCM, phase change material; PV, photovoltaic; PV/e, photovoltaic/evaporator; PVT, photovoltaic–thermal; SAHP, solar assisted heat pump; STC, standard testing condition; TE, thermoelectric; TEC, thermoelectric cooler; TEG, thermoelectric generator

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Nomenclature

β	temperature coefficient
ΔT	temperature difference
FF	fill factor
I	current
I_{sc}	short-circuit current
η	efficiency
P	power
T	temperature
V	voltage
V_{oc}	open-circuit voltage

1. Introduction

Solar energy is one of the most widely adopted renewable energy source that can be utilized in various applications such as, thermal management using thermal collectors or electricity generation through special optical solar cells, also known as Photovoltaic (PV) cells. PV cells are semiconductor devices that have the ability to convert the energy available in both dispersed and concentrated solar radiation into direct current (DC) electricity [1–6]. Conversion of solar energy into electricity through PV cells is achieved at different efficiency ratings varying between 7 and 40% and determined primarily by the type of semiconductor material from which the cells are manufactured [2,3]. PV technology has been adopted in many regions world-wide as solar energy is ubiquitous and abundant on the earth's surface. PV systems offer wide range of applications from direct power supply for appliances to large power stations feeding electricity into the grid and serving large communities. Although PV systems have been commercially available and widely operated for many years, certain barriers stand towards widespread application of this particular technology. Issues such as limited conversion efficiency, elevated temperatures, and dust accumulation are considered critical due to their significant impact on the performance of PV cells especially in sun-drenched hot climate regions. Wide range of cooling techniques for thermal regulation of PV systems has been investigated. Among the proposed systems, air and liquid based cooling of PV systems are considered mature technologies and have been practically tested widely. On the contrary, the utilization of heat pipe, phase change materials, and thermoelectric devices to aid cooling of PV cells still remain at the research and development stage. Although various techniques have been investigated, practical solutions have not been identified for wide implementation in large scale projects. The issue of elevated temperatures on the performance of PV systems and the research conducted to tackle this matter is addressed in this paper.

2. Temperature influence on photovoltaic cells

PV cells absorb up to 80% of the incident solar radiation, however, only small part of the absorbed incident energy is converted into electricity depending on the conversion efficiency of the PV cell technology used [4]. The remainder energy is dissipated as heat and the PV module can reach temperatures as high as 40 °C above ambient. This is due the fact that PV cells convert a certain wavelength of the incoming irradiation that contributes to the direct conversion of light into electricity, while the rest is dissipated as heat [6]. The photoelectric conversion efficiency of commercially available single junction solar cells ranges between 6 and 25% under optimum operating conditions depending on the semiconductor material from which the cell is made [3,5]. However, PV systems do not operate under standard conditions, thus variation of operating temperatures limit the efficiency of PV systems. Such limited efficiency is associated with the band-gap energy of the semiconductor material [1,6]. Crystalline silicon PV cells can utilize the entire visible spectrum plus some part of the infrared spectrum. Nonetheless, the energy of the infrared spectrum, as well as the longer wavelength radiation are not sufficient to excite electrons in the semiconductor material to cause current flow [6]. On contrary, higher energy radiation is capable of producing current flow; however, much of this energy is similarly unusable. Consequently, radiations with high and low energies are not usable by the PV cell for electricity generation, and instead are dissipated at the cell as thermal energy.

Various elements affect the performance of PV modules in outdoor applications. Factors such as low irradiance, soiling, and high operating temperatures contribute towards dramatic degradations in the conversion efficiency and the technical life-time of the solar cells [7,8]. PV cells however tend to be affected mostly by high operating temperatures due to irradiance from the sun, especially concentrated radiation which tends to further elevate the temperature of the PV junction. The PV cell performance decreases with increasing temperatures, fundamentally owing to increased intrinsic carrier concentrations which tend to increase the dark saturation current of the p–n junction [6,9]. Reduction in band-gap due to high doping also serves to increase the intrinsic carrier concentration [6]. The increase in dark saturation current causes the open-circuit voltage to decrease linearly which for silicon at 300 K corresponds to about -2.3 mV/°C [6]. Huang et al. [10] performed experimental investigation to observe the variation of open-circuit voltage with temperature

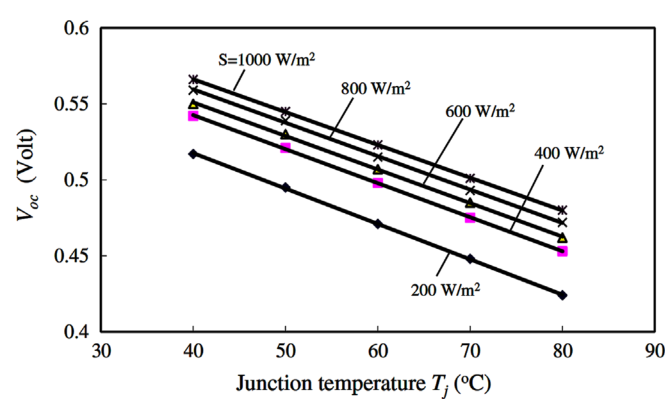

Fig. 1. Variation of open-circuit voltage with junction temperature of PV cell [10].

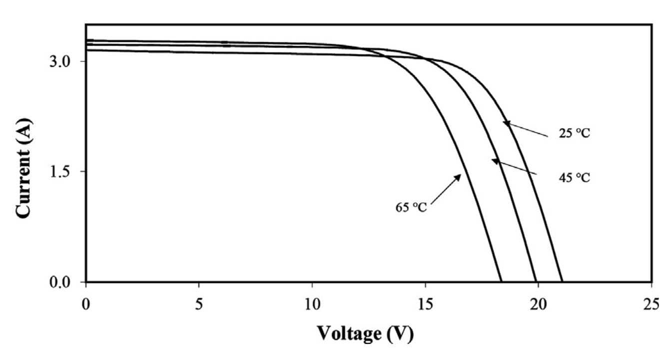

Fig. 2. Influence of temperature on PV module I–V curve [9].