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Photovoltaic thermal module concepts and their performance analysis: A review

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ABSTRACT

This paper presents a review of the available literature covering the latest module aspects of different photovoltaic/thermal (PV/T) collectors and their performances in terms of electrical as well as thermal output. The review covers detailed description of flat-plate and concentrating PV/T systems, using liquid or air as the working fluid, numerical model analysis, experimental work and qualitative evaluation of thermal and electrical output. Also an in-depth review on the performance parameters such as, optimum mass flow rate, PV/T dimensions, air channel geometry is presented in this study. Based on the thorough review, it is clear that PV/T modules are very promising devices and there exists lot of scope to further improve their performances. Appropriate recommendations are made which will aid PV/T systems to improve their efficiency and reducing their cost, making them more competitive in the present market.

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Contents

1. Introduction

Recent hike in oil prices has resulted in strong stimulation of research into renewable energy because such research can make major contributions to the diversity and security of energy supply, to the economic development and to the clean local environment. Renewable energy technologies currently supply 13.3% of the world's primary energy needs [1] and their future potential

Abbreviations: a-Si, amorphous-silicon; BIPV, building-integrated photovoltaic; c-Si, crystalline-silicon; COP, coefficient of performance; CPC, compound parabolic concentrator; CR, concentration ratio; pc-Si, polycrystalline-silicon; PV, photovoltaic; PV/T, photovoltaic/thermal; TMS, thin metal sheet.

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Nomenclature

A/A_C	ratio of heat transfer area to collector aperture area
A_C	PV/T collector area (m^2)
C_b	conductance of the bond between the fin and tube (W/m K)
C_p	specific heat of fluid (J/kg K)
d	outside tube diameter (m)
d_i	inside tube diameter (m)
F	fin efficiency
F'	collector efficiency factor
F_R	heat-removal factor
G	fluid mass flow rate per unit collector area (kg/s m^2)
G_T	solar irradiance (W/m^2)
h	heat transfer coefficient of fluid (W/m^2 K)
h_r	equivalent radiation coefficient (W/m^2 K)
k	thermal conductivity of the fin (W/m K)
Q_u	useful collected heat by collector (W/m^2)
T	temperature of PV module (K)
T_{ref}	PV module Reference temperature (K)
T_a	temperature of the ambient (K)
T_i	fluid inlet temperature (K)
T_f	average fluid temperature (K)
T_p	average plate temperature (K)
U_L	overall collector heat loss coefficient (W/m^2 K)

Greek symbols

δ	plate thickness (m)
η_{th}	PV/T thermal efficiency
η_{mp}	PV cell efficiency
$\eta_{mp,ref}$	maximum power point efficiency
$\mu_{P,mp}$	PV cell efficiency Temperature coefficient
$\tau\alpha$	transmittance–absorptance product

depends on exploiting the resources that are available locally and on overcoming the environmental challenges as well as winning public acceptance. Various forms of renewable energy depend primarily on incoming solar radiation, which totals about 3.8 million EJ per year. To harness the available solar energy resource effectively, the integrated photovoltaic combined thermal systems (PV/T) are especially attractive because the absorbed solar radiation is converted into electricity and heat which can be utilized simultaneously.

The main component of a photovoltaic/thermal (PV/T) system is a photovoltaic/thermal (PV/T) module, which is a combination of photovoltaic panel integrated to a solar thermal collector, forming one device that converts solar radiation into electricity and heat concurrently. PV/T modules have the ability to generate more energy per unit surface area than side by side PV panels and solar thermal collectors, at a lower production and installation cost. Because of its high efficiency per unit surface area, PV/T is particularly well suited for applications with both heat and power demand and with limited roof space available. In the Netherlands calculation done by ECN (Energy Research Centre of the Netherlands) [2] showed that it was possible to reduce the collector area by 40% with the use of PV/T collectors while generating the same amount of energy. Moreover, PV/T modules share the aesthetic advantage of PV. The incorporation of PV modules as part of the building envelope is a viable way of utilizing PV systems due to the combined provision of electrical power, heated air or hot water for use within the building. Large surfaces in the facade and roof of buildings are available and suitable for incorporating PV modules in them. Such incorporation has been referred as building-integrated PV (BIPV) technology and accounts for a significant portion in urban applications of PV systems in buildings.

2. PV/T development

The sun is the ultimate source for most of our renewable energy supplies and the direct use of solar radiation has a deep appeal to engineer and architect alike. Solar thermal collectors are used to convert solar radiation to thermal energy. In a thermal collector, a liquid or gas is heated and pumped, or allowed to flow through thermal convection, around a circuit and used for domestic or industrial heating. Photovoltaic cells are used to direct conversion of sunlight to electricity. The principal function of a PV cell is simple-silicon wafers convert the solar energy falling on them directly into electricity.

The most significant difference between solar thermal and photovoltaic system is that solar thermal systems produce heat and photovoltaic systems produce electricity. There are several methods to gather the solar energy and in a PV system most of the solar radiation that is absorbed is not converted into electricity. PV cells utilize a small fraction of the incident solar radiation to produce electricity and the remainder is turned mainly into waste heat in the cells, causing the increase of PV cell temperature hence the efficiency of the module drops. Cooling either by natural or forced circulation can reduce this PV cell temperature. An alternative to the PV cell is to use Photovoltaic thermal system (PV/T) (Fig. 1), where PV cell is coupled with heat extraction devices. The simultaneous cooling of the PV module maintains electrical efficiency at satisfactory level and thus the PV/T collector offers a better way of utilizing solar energy due to the increased overall efficiency. The attractive features of the PV/T system are:

- it is dual-purpose: the same system can be used to produce electricity and heat output;
- it is efficient and flexible: the combined efficiency is always higher than using two independent systems and is especially attractive in BIPV when roof spacing is limited;
- it has a wide application: the heat output can be used both for heating and cooling (desiccant cooling) applications depending on the season and practically being suitable for domestic applications;
- it is cheap and practical: can be easily be retrofitted/integrated to building without any major modification and replacing the roofing material with the PV/T system can reduce the payback period.

The concept of PV/T has been used and discussed for more than three decades by various researchers both experimentally and numerically. During the 1970s, the research on PV/T started, with the focus on PV/T collectors, with the main aim of increasing the overall energy efficiency. Domestic application was regarded as the main market. Initially the focus was on glazed collectors, both air type and liquid type, but soon the idea of an unglazed PV/T collector combined with a heat pump also received attention.

Like the thermal solar collectors, PV/T systems are categorized also according to the kind of heat-removal fluid used, hence PV/T water system and PV/T air system are common types, for water and air heat-removal fluids, respectively. PV/T water systems are more efficient than PV/T air systems [3], due to high heat conductivity and hence high heat capacity, high density-resulting in a high volume transfer. But use of water requires more extensive modifications to enable water-tight and corrosion-free construction.