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Review

Futuristic approach for thermal management in solar PV/thermal systems with possible applications

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A B S T R A C T

This paper aims to present a futuristic review on the potential of photovoltaic-thermal or PV/T systems in a wide spectrum for the efficient utilization of solar radiation through well engineered hybrid PV/T systems. These hybrid PV/T system based technology is just 30 years old which had gained significant attention from the researchers and academicians all over the world in a recent decade. The word PV/T is composed of [PV (photovoltaic) + T (thermal)] i.e. the simultaneous production of heat and electricity in an integrated manner thus paving the way towards improving the overall energy efficiency of the system. It is a sort of co-generation technology so that the issue of low efficiency associated with existing PV technology can be impact fully addressed. It provides an opportunity for the efficient utilizing of solar radiation which is eventually dissipated as waste heat in the PV cells causing decrease in the efficiency of the PV cells. This paper covers an extensive overview of the most recent trends and useful technologies available for thermal management in PV/T collectors in a categorical manner i.e. air based, liquid based, phase change material (PCM) based and heat pipe based along with wide range of possible applications in building, solar distillation /desalination and thermoelectric generators & heat pumps. The paper also covers economical aspects like payback period, concept of Net Present Value (NPV) and exergo-economic & enviro-economic parameters for the economic assessment of the PV/T systems. The results are being tabulated for visual understanding of the different techniques being reviewed. The paper also identifies the potential role of PV/T systems to mitigate emission challenges particularly with respect to building applications.

1. Introduction

Energy forms the basis for the economic development of any country and plays a significant role in improving the quality of life of the people living there. The importance of energy is apparent in almost every aspect of development and historical data reveals that there is a significant relation between the availability of energy and the economic activity. Though fossil fuel had played a significant and reliable role in this regard but its relentless use over a period of time had created serious problems of global warming and climate change [1–3].

The use of renewable energy especially solar energy in power generation as well as in domestic and building application has gained significant appreciation worldwide to meet the goals of sustainable development and environment conservation [4]. It has been estimated that solar photovoltaic will cover approximately 16% of the total energy production globally till 2050 [3]. Another important feature of solar energy based application is its feasibility to serve as decentralized stand alone system in the rural areas where access to grid is rather critical. In today's era of digitization the world is becoming shorter and compact day by day, so as the case with our gadgets and equipments which have became more compact and efficient in recent years? PV/T is a similar attempt in this regard to make a compact, cost effective and energy efficient system. Conventionally we have two different systems i.e. solar photovoltaic: for direct conversion of light into electricity and solar thermal collector: for air & water heating. The two systems work distinctly without affecting each other and require separate space to be deployed physically. Through PV/T collector it is possible to bring the two physically separated systems at one place in a single system through an integrated approach thus minimizing the land requirement and the system cost [5]. PV/T systems are effective not only from the view point of energy efficiency and energy conservation but also proves to be environment friendly and economical particularly when used in conjunction with buildings either as building added (BA) systems or building integrated (BI) systems. A significant reduction in annual CO_2 emission as well as in payback period is observed when PV/T systems are coupled with building [6]. Huide et al. [7] comparatively

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investigated the simulation model of hybrid PV/T collector with those of individual solar thermal and PV collectors for different cities. PV/T collectors were found to be the best energy saver with respect to energy consumption in buildings especially in urban areas with limited availability of space for the installation. Waeli et al. [8] had reviewed the progressive development in PV/T; initially during 80s the researchers were mainly focused on the design and application part; while 90s was the period of techno-economic improvement in the designs; however the last decade was mainly dedicated to the innovations and futuristic challenges in the PV/T systems. This work is focused on the extensive review of latest techniques and advancements in designing and wide range of PV/T applications particularly from 2010 onwards with special attention towards its future scope. Many designs depending upon the type of fluid (air, water, bi-fluid, nano fluid), depending upon the type of heat exchanger (serpentine, roll bond, sheet & tube), use of concentrating collectors to form (C-PV/T) and use of advance techniques through phase change materials and heat pipes have been extensively discussed. A wide range of PV/T based applications from domestic water heating & building applications to the most commercial ones like desalination/distillation, thermoelectric generators and heat pumps have been introduced which clearly indicates that PV/T collector is definitely going to change the existing structure of two distinctly separated collectors as required for heat and electricity into one single unit [3] (see Fig. 1).

1.1. Why PV/T?

The driving force behind the photovoltaic-thermal (PV/T) technology as shown in Fig. 2 can be grouped into following three conclusive points i.e. (i)-lowering the operating temperature of PV modules (ii)-improving the overall energy efficiency of the system and (iii)-minimizing the space requirement and system cost.

Photovoltaic thermal or PV/T systems as the name suggests is an integrated system a sort of co-generation to produce heat & electrical work simultaneously, while reducing the operating temperature of the PV panels in the desired range. It is now a proven fact that the performance of PV modules degrades with increase in cell temperature (0.45% reduction in efficiency for unit degree rise in temperature) and PV modules converts only 10–17% of the incoming solar radiation into useful work while almost 40–50% of the radiation is converted into heat which can cause serious damage to the PV systems [9–11]. So the basic idea of PV/T system is to somehow extract this heat via (air cooled, water cooled, natural & forced convection or immersion techniques) so that it can be used for various useful applications, otherwise a major portion of this heat get wasted [9]. This PV/T technology has gained a significant attention from the researchers & academicians from all over the globe in last 25–30 years. Various system designs, theoretical & simulated models are tested under various operating conditions so as to minimize the operating module temperature as well as to reach the higher values of temperature at the out let end of a PV/T collector in an efficient and cost effective manner. PV/T systems are the ideal example of co-generation producing heat & work in a single integrated unit, thus minimizing the space requirement and system cost. The payback period of a typical PV/T system in terms of both energy and green house gas is found to be in the range of 1–4 years [12]. However certain gaps have been identified by Kasaeian et al. [13] who reviewed these hybrid PV/T systems as an ideal source of combined heat and power (CHP) with extensive focus on exergo-economic evaluation and performance investigations of large scale systems.

1.2. Construction and working principle

The working principle behind PV/T system is to utilize the waste/excess heat, which is usually being lost and increases the operating temperature of the PV module, through an appropriate mechanism to be deployed at the back side of the PV module. The surface temperature of the PV module can reach up to 80 °C in absence of proper thermal management [9]. The basic structure of a PV/T system comprises of two main parts [(a)-PV module + (b)-T (thermal) part] as shown in Fig. 3. Notice that this ‘T’ or thermal part is the principle or key component of the PV/T system from the view point of thermal energy management.

Actually due to inherent conversion constraints associated with existing PV technology only a small part of the incoming solar radiation is utilized into useful electric work while a major portion is dissipated as waste heat in the cells which accounts for about (0.25–0.5%) reduction in electrical efficiency for each degree rise in cell temperature. So basic idea behind PV/T is to extract or remove this excess heat through various thermal management techniques using (air, liquids, PCM’s and heat pipes) discussed in section-2 for various possible applications in (buildings, solar desalination systems and heat pumps) discussed in section-3. Generally this ‘T’ or the thermal part of a typical PV/T system comprises of a thermal absorber, copper tubes, a heat transfer fluid, thermal insulation and casing shown in Fig. 4 [15].

1.3. Efficiency of PV/T system

Basically a PV/T systems is a fusion of a flat plate solar thermal collector and a photovoltaic panel in a single unit. The overall system

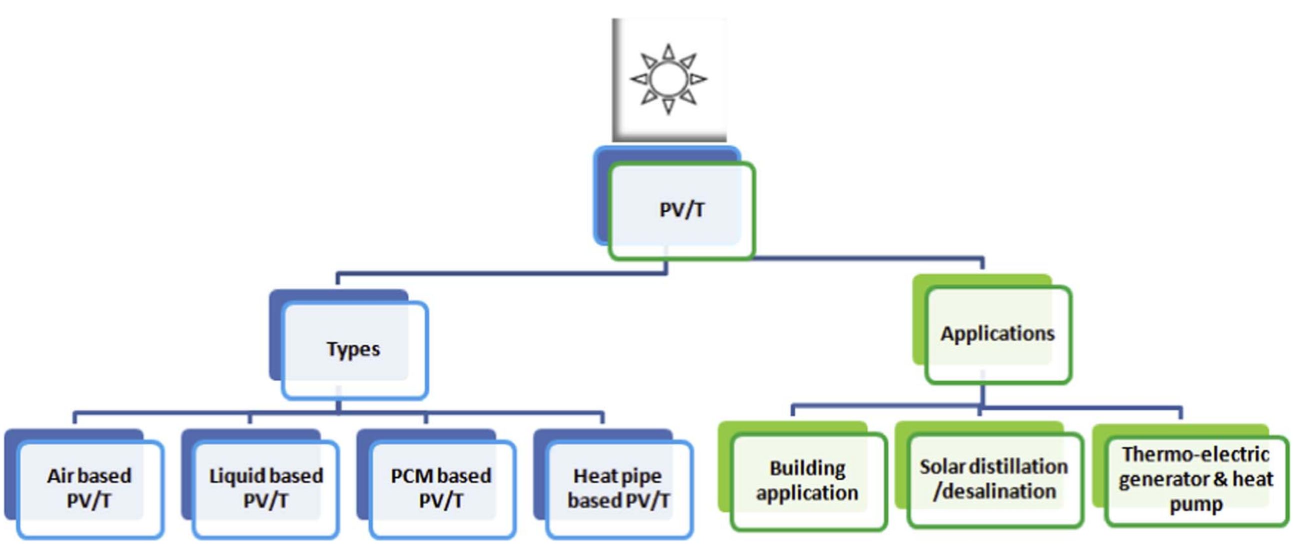

Fig. 1. Categorical description of different PV/T techniques with possible applications.