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A review on recent advancements in photovoltaic thermal techniques

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ABSTRACT

Due to ever increasing simultaneous demand of heat and electricity globally, Photovoltaic thermal (PVT) system comes out as an essential research area in recent years. Integration of photovoltaic (PV) and thermal system in a single unit, improves PV cell efficiency and produces low grade heat. Researchers are working on optimization of the PVT system from last 2–3 decades, but till now, very few efficient PVT systems are available in the commercial market. This review paper describes the work done by various researchers on conventional and newly developed PVT systems. Building integrated PVT system and some typical research works has been presented for novel PVT systems during last 5–6 years. Key information from different research work is summarized at the end of every section, so that the readers can identify and analyze the overall development in PVT systems. Future perception and recommendation on PVT systems are also discussed at the end.

1. Introduction

In the current world scenario, energy is the biggest issue that needs to be focused very aggressively. Energy has various applications almost in every sector like industrial, agricultural, medical, transportation, household and so on; and it may cause by 2035, the world energy consumption will be increased by more than 30% [1]. The availability and accessibility of energy are very important for the growth of individual and development of the country. As, the whole world will be facing scarcity of fossil fuels like coal, natural gas and oil in the near future, it is very important to work on the development and applications of renewable energy resources. Sun's solar energy is one of the most efficient choice of renewable energy resources; as it is clean, available freely and in abundant quantity. Solar energy can be easily converted into various other usable forms of energy like thermal energy, electrical energy and chemical energy.

The solar cell absorbs incoming photons from the sun and generates electricity with photovoltaic effect. In 2014, the International Energy Agency (IEA) released its report [2], indicated that, there will be 16% share of photovoltaic, in total energy production by 2050. According to renewable global status report 2016 [3], The solar PV market has experienced record growth in year 2015, 50 GW were added to the global energy production and the total global capacity with solar PV reached to 227 GW. But still, there were only 1.2% shares of solar PV out of 23.7% of total global renewable electricity production up to 2015. This shows that, globally, there will be huge demand for PV solar cells in near future. The photovoltaic solar cell has some serious issues like high initial investment cost, large installation area and less conversion efficiency. In recent years, huge research work has been carried out on improving efficiency and economy of solar cells; resulted in, the laboratory efficiency of multi-junction solar cell has reached up to 46% and si (crystalline) solar cell has crossed 25% [4]. About 80–85% of solar cell market is based on crystalline silicon solar cell, crystalline silicon solar cell absorbs about 90% of incoming solar irradiance ranging from 400 nm to 1200 nm. All the incoming solar irradiance falling on the PV cell does not converts into electrical energy, the conversion efficiency of crystalline silicon solar cell, available in the market is ranging from 12% to 18% [5]. The rest of the unpersuaded solar radiations, converted into heat instead of electricity and causes to raise the temperature of PV cell [6,7]. The efficiency of solar cell is usually measured at AM1.5 with 1000 W/m^2 of solar irradiance and at 25 °C temperature. The high temperature of PV cell has adverse effect on the performance of PV cell. The increase in temperature of PV cell causes, 0.06–0.1%/°C rise in its short circuit current, but; power output, fill factor and open circuit voltage decreased to 0.4–0.5%/°C, 0.1–0.2%/°C and 2–2.3 mV/°C respectively [8]. Solar energy is mainly harvested with two very matured technologies; the solar thermal technology to convert solar energy into thermal energy using solar thermal collector and solar photovoltaic technology to convert solar energy into electricity [9]. Solar thermal is one of the most developed solar technology and is available commercially at very effective cost. Solar thermal technology is being used very effectively in various domestic, agricultural and industrial applications. Wolf [10] first in the mid-1970s, integrated components of solar thermal system

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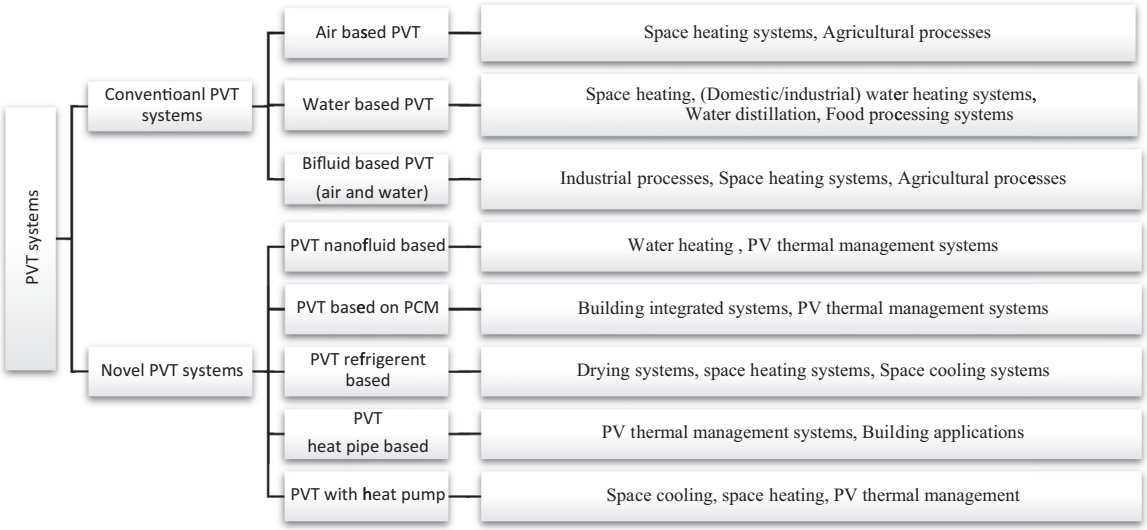

Fig. 1. Classification of PVT system based on heat transfer techniques and integration of PVT systems with different infrastructure.

and solar photovoltaic system in one unit. The integrated system could produce heat and electricity simultaneously from the single system. The main purpose to integrate both the system was to increase electrical efficiency by extracting waste heat during photovoltaic operation. The integrated unit was mainly known as a photovoltaic thermal system (PVT).

The PVT system produces electricity and low grade thermal energy simultaneously, low grade heat has various applications like space heating, industrial process heating, preheating industrial or household fluids, crop drying and so on. PVT system requires less space than individual PV and solar thermal systems; also, PVT systems can be installed at almost the same cost as that of individual PV and solar thermal system. PVT system have less production and installation cost per unit area and thus can be very significant in the compact infrastructures like in buildings, hospitals or in industries. PV panel in PVT systems usually maintained at lower temperature, it results in higher efficiency and longer life of PV panel due to prevention of decay of Si. Classification of PVT systems based on various heat transfer techniques and integration of PVT systems in different possible infrastructures are presented in Fig. 1. The PVT systems can again be classified depending on various system parameters like absorber plate design and fluid flow systems like natural circulation, forced circulation, single pass, double pass, number of channels and so on.

Understanding the importance of integrated photovoltaic thermal system, Huge experimental and numerical research work has been carried out in designing and optimizing a PVT system in last 2–3 decades, but still, very few efficient PVT systems are available in the market. Researchers had published many review articles on PVT technology, the main focus of majority of review articles was to evaluate overall research and development of each available PVT system [5,6,9,11–18], while some researchers reviewed separately; air based PVT system [19,20], water based PVT system [21], phase change material based PVT system [22,23] and so on. Recently, Aboghrara et al. [24] published a review article based on the effect of various climatic, design and operational parameters on the performance of PVT system.

The photovoltaic thermal system is in developing stage and still, there is a huge possibility for further growth and optimization of the already developed PVT system. Many researchers are working on improving performance of the conventional PVT system like air based and water based systems; while, some researchers have introduced few novel concepts in PVT technology like heat pipe, nanofluid and phase change materials. In last 4–5 years, tremendous research work has been carried out on PVT systems and thus, compilations of research work done by various researchers are very important to understand recent trends in PVT technologies and to take steps forward for further research and development to be carried out on PVT systems. This review article is mainly focusing on work done by various researchers during last 4–5 years in the field of PVT technology. Some conventional PVT systems like air based and water based systems are also reviewed, so that, the reader will be appraised of the overall development in PVT technology. Summary of important PVT techniques and/or characteristics of thermal systems is presented at the end of every section, so as to get the key information regarding technological development in PVT systems at a glance.

2. Conventional PVT systems

Performance and applications of PVT system depend on its heat transfer fluid. Conventionally, air and water are being used as a thermal fluid in PVT systems. During last 3–4 decades, plenty of research work has been carried out on optimization of conventional fluid based PVT systems. In the subsequent sections, typical research work based on air and water as a heat transfer fluid in PVT systems is reviewed. Important findings, different system configurations and efficiencies are presented in a tabular form at the end of the section.

2.1. PVT air based

In air based PVT systems, air is allowed to pass through the PV surface with either active or passive mode, using single or double pass and through different absorber configurations. Earlier research work on air based PVT systems were mainly carried out for its performance enhancement. Many researchers worked on optimization of its design, operation and materials; while, some research work are reported on simulations and development of a numerical model.

Single pass and double pass PVT systems for air heater were designed and analyzed by Sopian et al. [25]. Performance of designed PVT air heater systems was studied for both the cases with different values of flow rate, packing factor, collector length and duct depth. They confirmed 24–28% thermal efficiency and 30–25% combined efficiency for single pass, while, 32–34% thermal efficiency and 40–45% combined efficiency in double pass PVT air heater systems. PV cell efficiency was observed to be higher for the double pass system compared to single pass PVT air heater system.

Garg and Adhikari [26] developed and simulated hybrid PVT air collectors model. Single glass and double glass configurations were used for analysis. Parametric studies confirmed that system efficiency