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A review of the concentrated photovoltaic/thermal (CPVT) hybrid solar systems based on the spectral beam splitting technology

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HIGHLIGHTS

- A review on spectral beam splitting (SBS) CPVT technologies is presented.
- SBS methods including interference, liquid absorptive and other filters are discussed.
- The researches of SBS CPVTs are reviewed comprehensively and summarized.
- Recent research status and system performance characteristics are analysed.
- Suggestions on the development of SBS CPVT technologies are proposed.

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ABSTRACT

This article presents a review on the research and development of spectral beam splitting concentrated photovoltaic/thermal (SBS CPVT) hybrid solar systems. The investigations on the SBS CPVT hybrid technologies had begun in the 1980s and were aimed at complete utilization of the solar irradiation over the whole solar spectrum using both PV cells and thermal absorbers. Several different SBS approaches were employed to achieve better conversion efficiencies, including the interference filter, liquid absorptive filter, holographic filter, luminescent filter, diffractive filter, combined interference and liquid absorptive filter, combined liquid and solid absorptive filter, and photovoltaics itself as a solid absorptive filter. The SBS CPVT systems were proposed or assembled in various system configurations for numerous purposes, such as domestic hot water, thermochemical reaction, hydrogen production, or even power generation. These researches and developments are comprehensively reviewed in this article, and the advantages and disadvantages of different SBS methods are presented and concluded. This paper also aims to provide a global point of view on research trends, market potential, technical obstacles, and the future work required for the development of SBS CPVT technology.

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1. Introduction

Solar energy is one of the ideal alternative energy resources, especially, since it is free and inexhaustible. As only a tiny fraction of the solar radiation on the Earth can cover the global energy demand in the future, technologies for the conversion of sunlight, such as photovoltaics (PV), photothermal, and photochemistry were deeply investigated and rapidly developed during the past decades. Among these technologies, PV has been developed to an advanced stage. Presently PV has become the third most important renewable energy source after hydro and wind power. By the end of 2014, the terrestrial PV systems installed all over the world had a total capacity of over 150 GW [1].

Despite the great progress in PV technologies, the conversion efficiencies of PV systems need to be further improved. For PV, although the 4-junction solar cells, manufactured by ISE institute of Fraunhofer, recently hit a new conversion efficiency record of 46.0% [2], the conversion efficiencies of commercialized PV systems are, however, still low; for e.g., 14–20% for silicon solar cells and 25–30% for III–V multi-junction solar cells [3]. Most of the remaining solar energy is dissipated as heat.

In order to make efficient use of the solar energy, different kinds of photovoltaic/thermal (PVT) hybrid technologies were developed for combined heat and power (CHP) cogeneration since the 1970s [4]. The flat-plate PVT hybrid system, without concentrating the solar irradiation, was developed in order to extract both electrical and thermal energy from PV cells. Water or air are typically used as the coolant and heat transfer fluid (HTF) flowing over the entire plate. As reviewed by Tyagi et al. [5] and Chow [4], the total cogeneration efficiencies of these flat-plate PVT systems are always higher than that achieved using two independent systems. In addition, the integration of PV and thermal collectors can reduce the production and installation costs, which makes it cheaper and more practical for applications that require both electricity and heat, such as building-integration installations [6].

However, the flat-plate PVT can be further improved by the use of an optical concentrator, which leads to the concentrated photovoltaic/thermal (CPVT) hybrid system. Compared to the flat-plate PVT, the CPVT system uses an imaging or non-imaging optical concentrator as the collector to provide a high intensity illumination to a much smaller solar cell receiver. As the area of the solar cells can be significantly decreased, expensive components, such as high conversion efficiency solar cells (e.g., III–V solar cells) and tracking systems can be employed to increase the electricity output. Furthermore, the increased solar intensity makes the HTF of over 80 °C available, which will expand the application field of the solar energy system, such as district heating, absorptive cooling, and water desalination. The area occupation of the solar energy system may also be reduced owing to the adoption of the tracking system, which would compensate the costs.

With the rapid development of concentrated photovoltaics (CPV) and solar thermal technologies, especially the concentrated solar power (CSP) [2,7], the high efficiency solar cells and the optical concentrating system become commercially available and their costs keep decreasing. The CPVT technology, which combines the two solar energy utilization methods, appears to be more attractive. A significant amount of research and development work on CPVT has been conducted during recent years. The configuration and performance of CPVT systems have been recently reviewed by Sharaf and Orhan [8,9], providing clear points of views on the CPVT systems with different hybridizations, covering systems with different types of optical elements, and PVT modules for various applications. The pre-illumination CPVT systems, which are also recognized as the CPVT systems using spectral beam filters, were discussed in detail and compared with the post-illumination CPVT systems in their articles. They concluded that the CPVTs with spectral beam splitting (SBS) technologies could "offer significantly higher HTF outlet temperatures without sacrificing electrical efficiency", and "this would noticeably broaden the spectrum of CPVT system-integration options".

However, although the development of CPVT systems using spectral beam filters has been summarized in some review papers discussing PVT/CPVT systems (such as the reviews of Sharaf and Orhan [8,9], Tyagi et al. [5], Chow [4], and Zhang et al. [10]) or SBS technologies for solar energy conversion (such as the reviews of Imenes and Mills [11] and Mojiri et al. [12]) this type of CPVT system is still not systematically and comprehensively reviewed yet. Since these reviews were not particularly focused on the SBS CPVT systems, some of the emerging concepts and new hybridization techniques were not included in the reviews. A review focusing particularly on the SBS CPVT systems is beneficial for us to understand its special components and system configuration, performance superiority, application fields, research trend, and technical obstacles.

This article aims to provide an up-to-date comprehensive review on the research and development of CPVT systems using SBS technologies. Basic conceptions of this type of CPVT systems are introduced in Section 2. Research documents on different types of the SBS CPVT system are introduced in Section 3, including the hybrid systems using interference filters, liquid absorptive filters, holographic filters, and other filters. The researches are further categorized according to the hybridization approaches. Research status, advantages, and disadvantages of these SBS methods are also presented. In Section 4, the summary of the information extracted from the literature is discussed. Finally, the research trend, market potential, technical obstacles, and the future work required for the development of this technology are concluded in Section 5.