Renewable and Sustainable Energy Reviews 76 (2017) 1108–1121

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Design and development of compound parabolic concentrating for photovoltaic solar collector: Review

Ahed Hameed Jaaz*, Husam Abdulrasool Hasan*, Kamaruzzaman Sopian, Mohd Hafidz Bin Haji Ruslan, Saleem Hussain Zaidi

Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

ARTICLE INFO

Keywords:
Compound parabolic concentrator
Photovoltaic thermal
Solar energy
Solar concentrating photovoltaic

ABSTRACT

Despite about five decades of development, commercial solar energy has not yet unable to penetrate the electric and gas options. For this particular reason, designing compound parabolic concentrators-photovoltaic thermal solar collectors (CPC-PVT) continues until achieving similar or greater performance with a comparative cost. This paper outlines the various types of CPC-PV systems concerning design advantages and limitations. The article includes comparisons on used materials, optical tolerance and efficiency, and the range of the acceptance angle. The review focuses on the historical developments regarding the use of Fresnel lens for optimizing captured sunlight, 2- and 3-D CPC, parabolic trough, and materials used for coating. It is hoped that this review helps researchers to highlight the successful trends of designing CPC by sorting out the many layers and factors that are decisive in designing CPCs. It can be seen clearly the vast opportunities for developing better designs and utilizing the qualities of the material used for reflectance and absorbance. Flat plate collectors have shown an increasing drawback to deal with temperatures of more than 100 °C. The fixed orientation of CPC has a ydisadvantage due to the limitations of capturing sunlight; however, tracking mechanism could be employed to enhance the amount of the captured sunlight. The non-imaging system is also highlighted to show its efficiency over the imaging systems concerning larger accept angles, higher concentration ratios with less volume and shorter focal length, higher optical efficiency. However, for applications such as solar-to-electric conversion, imaging, and non-imaging Fresnel lens have shown almost same conversion factor. Throughout CPC designing, particular issues have to be considered such as the ratio of reflector-to-aperture size, the formation of hot spots, and the minimising of losing of multiple reflections concentrating photovoltaic (CPV) systems are still developing where new methods, designs, and materials are still being created in order to reach a low levelled cost of energy comparable to standard silicon-based PV systems. It is very important to note that non-imaging Fresnel lenses could bring a breakthrough in commercial solar energy concentration application technology very soon.

1. Introduction

The conventional energy has caused severe damage to the environment in many aspects such greenhouse and global warming. The renewable energy has become the best alternative. However, the shift from the conventional energy to the green energy faces challenges characterized by availability, sustainability as well as the economy factor. Currently, the focus on solar and wind energy is the prime effort toward green energy [1]. Regarding the solar energy, the availability of the sun-light during half a day in most countries and the easy process of gathering the solar energy result in advancing this field scientifically and technologically to reach a very advanced level of reliability and acceptability during the last two decades.

In 1947, Winston [2] invented the first type of the compound parabolic concentrator (CPC) which is shown in Fig. 1 with most possible dimensions. The CPC can be stationary or with a compound rotation or translation [3]. The solar technology depends on gathering and reflecting the solar rays available in the sun spectrum. The efficiency of gathering and reflecting the sunrays depend on designing CPC. Regarding the use of the solar energy, it can be used directly for heating or store in photovoltaic cells (PVs) [4–8]. The direct conversion of solar radiation into electric power is traditionally more convenient than conversion into heat due to several reasons such a maintenance, safety, and long operation [9].

The solar power generation was reviewed by numerous articles [11–14] along with the analysis of the power generation [10,14–19].

* Corresponding authors.
E-mail addresses: eng_tay83@yahoo.com (A.H. Jaaz), hussam2003hussam@yahoo.com (H.A. Hasan).

http://dx.doi.org/10.1016/j.rser.2017.03.127
Received 2 December 2016; Received in revised form 5 February 2017; Accepted 27 March 2017
1364-0321/

Nomenclature

CPC	compound parabolic concentrators
PVs	photovoltaic cells
DC	direct current
θ_{max}	angle of acceptance
PMMA	polymethylmethacrylate
FPSC	flat plastic static concentrator
PVC	photovoltaic concentrating
MPPT	maximum power point tracking
P	power
I	current
V	voltage
P_{max}	maximum current
PVT	photovoltaic thermal solar collectors
CPV	concentrating photovoltaic
CCPC	crossed compound parabolic concentrator
TEG	thermoelectric generator

The surface modifications and design were discussed in [20–22]. The imaging and non-imaging systems are outlined in [23–27]. The PV cells are integrated into the solar system [7,28–31].

The non-imaging CPC was designed first in the mid-1960s and then developed by Winston [2]. The design of CPC consists of two parabolic reflectors at the two ends of the absorber. The 2-D CPC can receive radiation through a very big angular spread and can be still focused onto a linear receiver. The main purpose of the design was to collect as much as possible rays and then direct them by reflection either to a heat exchanger for heating or directly to PV cells collectors for electricity production. CPC is a non-imaging concentrator, which does not require the rays be parallel, or aligned with the axis of the concentrator.

CPC consists of receiver, cover, and reflector. The receiver of silicon polymer (emissivity 0.4 and absorbance 0.9) is characterized by the highest possible absorbance of the sunrays and should be fabricated using metals of very high conductivity. The cover is made of transparent insulating materials to allow perfect passage of solar radiation such as a glass of 4 mm thickness. The third part of CPC is the reflector, which should have the ability focus the reflected beam onto a receiver. In designing a CPC, all these factors have to be considered. The performance of CPC with accurate design and suitable materials could reach the highest level with concentration ratio between 3 and 10. Recently there have been many attempts to improve the overall efficiency of the solar cell by utilizing the recent development in plastic technology, nanocomposites, molding techniques, and computer-aided technology.

There are three levels of research in solar energy focusing on low, medium, and high concentration systems [32]. The first category is for concentration ratios between 1 and 10, where integrating the system into homes and small buildings becomes possible without complex mounting. It is also possible for these systems to use standard PV cells that were made for non-concentrating applications. The drawback of these systems is to cool down the PV cells which requires difficult maintenance. The middle level of research, where the concentrating ratios between 10 and 100, requires only one-axis tracking and the concentrators are symmetric. This system is based on parabolic reflectors [33]. The design of the PV cells has to consider high intensities (high current) where the cells need cooling during the collecting light. The system of a medium level is not suitable for installation for houses and small buildings. The third level, the highest, where the concentration ratios are between 100 and 1000. For this system, the sunrays are to be tracked using 2-axis system. The purpose of the high-level system is to generate high temperature suitable for a steam turbine to generate electricity. For this high-level system, parabolic dish or spherical lenses are used to concentrate the light onto PV cells. In this paper, a brief review of the most important designs of solar energy, which highlights the principles of the technical developments and usages.

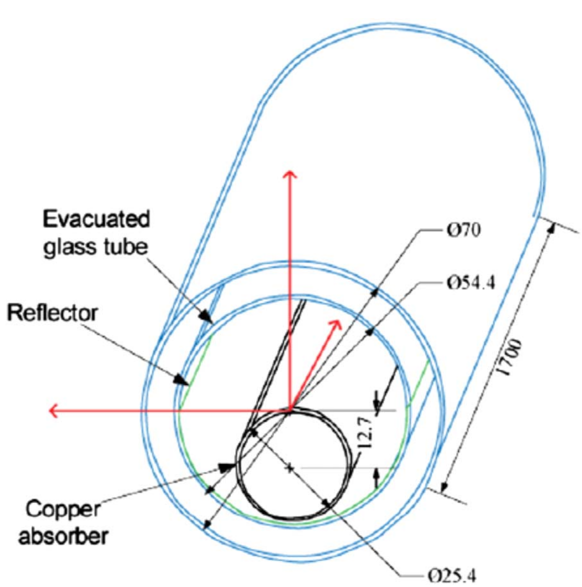

Fig. 1. Typical CPC with main dimensions [10].

2. Concentration ratio

As shown in Fig. 2, rays incident at the extreme angle of acceptance (θ_{max}) at the edge of the aperture are transported to the rim of the exit aperture [26]. If all rays are transported, the ideal case scenario is accomplished suggesting an ideal concentrator. This means that all rays can be gathered bounded by the phase space volume from a to a' and by directional space $\pm\theta_{max}$, which represents the limitations of the aperture.

Fig. 2 shows the basic principles of the majority of designing architecture for the flat absorber. In Fig. 2(b), the rod AC is placed at the aperture tilted by θ_{max} with the horizontal through which the parabolic absorber ac accepts all possible rays. This is the principle of the parabolic concentrator with its focal point at point d and the optical axis is cC. By applying Fermat's principle of an equal optical path, the edge ray yield (Eq. (1)):

$$Cc+cd = ad+easin\theta_{max} \tag{1}$$

For symmetric shape of Fig. 2(b), $Cc = ad$, then, $cd = ea\sin\theta_{max}$. The concentration ratio is defined as the entry aperture divided by the exit aperture (Eq. (2)),

$$C = \frac{ea}{cd} = \frac{ea}{easin\theta_{max}} = \frac{1}{sin\theta_{max}} \tag{2}$$

The geometry of 2D-CPC is shown in Fig. 3 with the basic construction of CPC of aperture (GF=W), absorber (AB =b), and the collectors of two parabolas, (AG) and (BF). Fig. 3(b) shows more details regarding the dimensions, the angles, and the axes of CPC. The distance between the reflector (AB) and the aperture (GF) represents the height of the CPC. The aperture area, $A_{aperture}$, is the product of W and the length (L) of CPC (not shown in the figure) (Eq. (3)) while the absorber area,$A_{absorber}$, is the product of b and the length (L) of CPC as depicted in Eq. (4).

$$A_{aperture} = W*L \tag{3}$$