Alexandria Engineering Journal (2016) 55, 1–11

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Alexandria University

Alexandria Engineering Journal

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ORIGINAL ARTICLE

Mechanical design of a low cost parabolic solar dish concentrator

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Received 10 October 2015; revised 21 January 2016; accepted 27 January 2016
Available online 13 February 2016

KEYWORDS

Parabolic dish;
Solar energy;
Low cost

Abstract The objective of this research was to design a low cost parabolic solar dish concentrator with small-to moderate size for direct electricity generation. Such model can be installed in rural areas which are not connected to governmental grid. Three diameters of the dish; 5, 10 and 20 m are investigated and the focal point to dish diameter ratio is set to be 0.3 in all studied cases. Special attention is given to the selection of the appropriate dimensions of the reflecting surfaces to be cut from the available sheets in the market aiming to reduce both cutting cost and sheets cost. The dimensions of the ribs and rings which support the reflecting surface are optimized in order to minimize the entire weight of the dish while providing the minimum possible total deflection and stresses in the beams. The study applies full stress analysis of the frame of the dish using Autodesk Inventor. The study recommends to use landscape orientation for the reflective facets and increase the ribs angle and the distance between the connecting rings. The methodology presented is robust and can be extended to larger dish diameters.

1. Introduction

In the last ten years, oil prices became very high as well as the reserves amounts have been decreased. Moreover, burning fossil fuels such as coal, oil and natural gas for energy generation causes global warming and pollution problems. Based upon these facts, new resources of clean energy are necessarily needed. Renewable energy is the promising solution to this problem. Therefore, significant researches have been reported on how to utilize renewable energy resources efficiently. One of the most important resources of renewable energy is the solar energy which has widely spreading applications. It has been used for water heating, direct electricity generation by means of photovoltaic, and for steam generation using parabolic trough solar collectors. It is estimated that earth receives approximately 1000 W/m^2 amount of solar irradiation in a day [1]. Abbot [2] showed that this amount of irradiation could generate around 8500 TW worldwide and concluded that solar energy alone has the capability to meet the current energy

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.01.028
1110-0168

Nomenclature

a	the distance from the focal point to the vertex	$\mid L$	sum of the perimeter length of unfolded facets to be cut from the reflecting sheets
b	width of the cross-sectional area of the rib	n_f	factor of safety
d	distance between any two consecutive rings	W	weight of the dish frame
D	diameter of the dish	α	angle between any two consecutive ribs
FD	ratio of focal point position to dish diameter	δ	total deflection
FP	position of the focal point	σ	stress
h	height of the cross-sectional area of the rib		

demand. This has been confirmed based on theoretical calculation by Liu et al. [3].

Nowadays, there are numerous projects regarding the implementation of the solar concentrators. These projects have been done by research centers, universities and companies to design and to analyze the reliability and the performance of solar concentrator. Among the solar concentrators, parabolic dishes have the highest efficiency in the conversion of solar energy to electricity with an efficiency of 29.4% achieved [4]. Such systems have high optical efficiencies and low start-up losses leading to highly efficient solar energy engines. This gives the parabolic dishes the potential to eventually become one of the least expensive forms of renewable energy. Moreover, parabolic dish systems are typically designed for small-to-moderate capacity applications of the order of ten kilowatts which are suitable for remote power needs in rural areas and the places far away from the national electricity grid. In case of higher capacity needs, it is easy to install smaller capacities of the solar dishes connected together in a small farm [5]. Although parabolic dish concentrators offer the highest thermal and optical efficiencies among all solar concentrators demonstrated to date, they suffer from a higher cost of construction per unit area, compared to parabolic trough and Fresnel linear systems. Most of the studies carried out on parabolic dish concentrators have been focused on the thermal analysis of the solar energy conversion process including the engine. Johnston et al. [6] studied the optical losses in the spherical elements of the reflective surface of the dish. García et al. [7] presented a detailed thermal analysis of the Eurodish solar Stirling engine developed at the premises of the Sevilla Engineering School, Spain. The dish was designed to produce 10 kW. Wua et al. [8] had designed an improved version of the Solar/Stirling engine that could produce about 20 kW electricity through AMTEC project. It can be noted that the sizes of the parabolic dishes have been increased within the last two decades with the development of new technologies and the progress of automated fabrication. Lovegrove et al. [5] in the Australian National University had worked on dish systems for many years and his team developed 400 m^2 and 500 m^2 [9] dishes in the last decade. However, most of the implemented systems are still expensive and require large parcel of land. Therefore, designing a solar dish with small to moderate size with low cost to generate direct electricity is an important issue. Palavras [10] worked on the development and performance characteristics of a low cost dish solar concentrator and its application in zeolite desorption. An old damaged satellite dish purchased from a scrap yard was used. The reflecting surface was a polymer mirror film. It is concluded that a low cost is achieved compared with other previous work through the use of polymer film instead of curved glass mirror or polished aluminum mirror. A low cost solar steam generating system design, development and performance characteristics were investigated in [11]. Preliminary field measurements and cost as well as performance analysis of the system indicated that a solar to steam conversion efficiency is 70–80% at 450 °C.

Noting that little work has been done in the area of lowering the cost of solar dish, this paper demonstrates the mechanical design of low cost parabolic solar dish concentrator with small-to-moderate size for direct electricity generation. The strategy implemented in this study considers the following directions: (a) minimize the torque required by the motor to track the sun rays, (b) find the optimum distribution of the reflecting sheets which will be cut from stainless steel sheets available in the market, and (c) design a robust dish frame with minimum weight to support the entire engine and dish weight as well as expected wind forces. Different dish diameters have been studied with full stress analysis of dish frame using Autodesk Inventor.

2. Description of the components of the system

The parabolic dish solar concentrator system mainly consists of base support, concave dish frame, reflecting sheets, conversion unit and sun-tracking system as shown in Fig. 1. The tracking system is dual axis tracking system with slew drivers. The first slew driver ensures rotation of the concentrator around the vertical axis through all possible azimuth angles while the second slew driver ensures rotation of the concentrator around the horizontal axis through all possible elevation angles. There are two systems to handle the entire dish with the converting unit. Either to locate the base frame exactly at the CG point of the entire dish in order to reduce the torque on the transmission system or set it behind the entire dish. The present study implements the first technique, which has been designed and implemented by different companies in the market [12,13]. Intentionally, the axes are passing through center of gravity of the dish in order to avoid using counter weight and consequently reducing the needed driving torque. All these parts have to function properly to have an efficient system. However, from cost viewpoint, each of these parts has to have minimum cost as possible. Special attention has been given to lower the cost of preparing reflective sheets as well as to minimize the weight of the dish