DESIGN AND PERFORMANCE EVALUATION OF LINEAR SOLAR CONCENTRATOR-PHOTOVOLTAIC SYSTEMS

by

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CERTIFICATE

It is hereby certified that thesis entitled, "Design and Performance Evaluation of Linear Solar Concentrator-Photovoltaic Systems" which is being submitted by Shivendra Nath Sharan is entirely the result of the candidate's own efforts, carried out under my supervision. This report, has not been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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SUMMARY

This thesis presents the thermo-electrical performance studies of some linear solar concentrator - photovoltaic systems. In the begining bibilography survey of the literature has been made. A theoretical modelling of combined linear solar concentrator-thermal-receiver system for two different receiver configurations (e.g. flat vertical and tubular) has been made.

Analysis for obtaining optimum value of concentration ratio for flat horizontal and flat vertical receivers have been made by taking into account both series resistance as well as the temperature effect on the efficiency of solar cells.

The economic feasibility studies of such a linear solar concentrator - photovoltaic system has been made and lower/upper bound of some of the design and cost parameters have been obtained. A formulae for determining the cost of unit of electricity produced by such system has been developed which includes all the design, operational and cost parameters.

A linear Fresnel Reflectors with flat vertical receiver (i.e. fin type), and a polygonal Trough with flat horizontal, flat vertical, and tubular receiver have been designed, and their concentration characteristics have been studied.

Results of the experiment made with a prototype of a linear solar concentrator-photovoltaic system consisting of flat horizontal receiver have been obtained at the end of the thesis.

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SUMMARY

Presently the cost of unit of electricity produced by a simple photovoltaic array is much higher than the cost of unit of electricity produced by conventional methods [1]. Two possible ways of reducing the cost of unit of electricity produced by solar cells are being advocated for the last few years [2-9]. One of the approaches is to improve the cell fabrication technology to obtain a considerable reduction in the cost per unit area of solar cells alongwith a simultaneous increase in their conversion efficiencies. Another approach being considered for the desired cost reduction is to make use of solar concentrators so as to replace the expensive solar cell area by comparatively cheaper mirror/lens material.

A concentrator-photovoltaic system usually consists of a concentrating device (mirror or lens or a combination of both), an absorber mounted with solar cells, a tracking device (if necessary) and an active/passive cooling arrangement to maintain the temperature of the solar cells at a desired level [10-14]. R & D workers in various parts of the world are actively engaged in one or more of above constituents of concentrator-photovoltaic systems [13]. The present work is also devoted to some analytical and experimental studies of such systems.

The use of concentrators for thermal utilization of solar energy at higher temperatures has long been

practiced [1[illegible]-18] . Recently, some efforts have also been directed to (i) modify existing concentrator designs and (ii) to develop somewhat novel concentrator designs which can be advantageously used with solar cells. In view of this, composite solar concentrators made up of smaller flat mirror elements have been found to give relatively better optical performances. The geometrical-optical performance of two such linear composite solar concentrator designs have been analysed in the present work.

Besides the possibility of a reduced cost of unit of electricity a properly designed concentrator photovoltaic system may provide useful thermal output as well. Such combined photovoltaic-thermal concentrator receiver system have received considerable attention recently [13] Although some efforts have been made to model such system to predict their electrical and thermal outputs, a detailed investigation for various concentrator-receiver geometries is necessary to exploit their full potential. In the present work two such systems have been analyzed.

It is well known that with an increase in the concentration ratio the current density increases linearly resulting in an increased potential drop across the series resistance of a solar cell [61-69] . This ultimately leads to an optimum value of concentration ratio corresponding to the maximum efficiency. It should, however, be noted that in almost all practical systems the true optimum value of concentration ratio should also depend on the operating temperature of the solar cell. This necessitates the development of an approach which combines both the series resistance as well as temperature effects on the efficiency of the solar cell. Some preliminary considerations towards the development of such an approach have also been presented in the proposed thesis.

The large scale utilization of concentrator-photovoltaic systems for generation of electricity (and thermal energy, if desired) depends on the cost of unit of electricity produced by them. It is, therefore, very important to study the economic feasibility of such systems as compared to that of simple photovoltaic arrays. Some such preliminary studies are available in the literature [100 -107] . In the present work an attempt has been made to establish conditions under which the concentrator-photovoltaic system would be economic. Formulae for determining the cost of unit of electricity produced by photovoltaic-concentrator systems for both passive as well as active cooling arrangements have been obtained. The sensitivity of the results obtained to the probable errors in estimating various input parameters have also been studied.

Finally, the results of some experiments performed on a simple prototype concentrator-photovoltaic system have also been included in the present work. A chapterwise summary of proposed thesis is given below.

CHAPTER - I

This chapter presents a detailed review on concentrator-photovoltaic systems. Efforts have been made to include all the available literature on such systems. The chapter briefly summarizes the present state of art of two major constituents of concentrator-photovoltaic systems - solar cells and solar concentrators. A brief review of the R & D work done on the combined photovoltaic-thermal concentrator receiver systems, on the optimization of concentration-ratio and on the economics of such systems have also been presented. Finally, the chapter also presents typical case studies of such systems, installed in various parts of the world.

CHAPTER - II

This chapter deals with the theoretical performance evaluation of linear concentrator-photovoltaic systems with combined electrical and thermal energy production. Two types of absorbers have been analysed for this purpose. The first one is the flat vertical absorber having solar cells mounted on its two sides while the second absorber has a circular cross-section (i.e. a tubular absorber). The distribution of the solar cell and coolant temperature along the length of the absorbers have been studied which is then used to obtain expressions for thermal and electrical energy outputs. Some numerical calculations have been made and presented graphically.

CHAPTER - III

A some what new approach for determining the optimum value of concentration ratio for a combined photovoltaic-thermal concentrator-receiver system has been discussed in this chapter. This approach takes into account both the series resistance and temperature effects on the performance of the solar cells. Numerical calculations made in this connection indicate that when one takes into account both the series resistance as well as temperature effects the optimum shifts to lower values. It has also been found that in a practical system, the optimum concentration ratio will depend on several design and operational parameters such as the coolant mass flow rate, length of the absorber, various heat transfer mechanisms, shape and size of the absorber, and the optical efficiency of the concentrator-receiver system.

CHAPTER - IV

Some preliminary economic considerations on the feasibility of concentrator-photovoltaic system have been presented in this chapter. An attempt has been made to identify the conditions under which the cost of unit of electricity produced by a concentrator-photovoltaic system would be less than the cost of unit of electricity produced by simple photovoltaic arrays. These lower/upper bounds on some of the pertinent design and cost parameters have been obtained on the basis of a present to present and future to future comparison of the cost of unit of electricity produced by concentrator-photovoltaic systems and simple photovoltaic arrays. Cost functions available in the literature for the cost per unit area of concentrator and the cost per unit area of the solar cell have also been used while establishing these bounds. Results of some exemplifying calculations have been presented in tabular form and a discussion of the results is also included. Formulae for determining the cost of unit of electricity have also been developed. Using these formulae and the most probable estimates for the various parameters some numerical calculations have been made. A sensitivity analysis has also been made to study the relative effectiveness of the various design, operational and cost parameters on the cost of unit of electricity produced by concentrator-photovoltaic systems.

CHAPTER - V

Design and geometrical-optical performance characteristics of two linear composite solar concentrator receiver system have been presented in this chapter. The first design is a linear Fresnel reflector using a flat vertical absorber. The second design is that of a polygonal trough and has been studied with three different absorber configurations-flat horizontal, flat vertical, and tubular. The distribution of local concentration ratio on the surfaces of the absorbers has been studied using analytical technique. The results are plotted graphically and discussed.

CHAPTER - VI

The results of various experiments conducted to study the performance of the combined photovoltaic-thermal-concentrator-receiver system have been presented in this chapter. The experimental studies include following results -

(i) Variation of electrical power output and the electrical conversion efficiency with time during the day.

(ii) Variation of the coolant temperature and the thermal power output along the length of the channel.

(iii) Variation of coolant temperature, thermal output and electrical output with mass flow rate for a given length of absorber.

The above mentioned work has partially appeared in the following publications.

Journals :

1. Design and raytrace evaluation of polygonal trough solar concentrators, Optica Applicata, 16(1986), 35.

2. Economic evaluation of concentrator-photovoltaic systems, Solar and Wind Technology, 2 (1985), 195.
3. Economic Feasibility of Photovoltaic-concentrating systems, Solar Cells, 15(1985), 199.
4. Estimation and sensitivity analysis of the cost of electricity produced by concentrator-photovoltaic systems, Energy Conversion and Management, 26(1986).
5. Analysis of an actively cooled photovoltaic-thermal solar concentrator-receiver system using fin type absorber, Solar and Wind Technology, (In Press, 1986).
6. Analysis of a combined photovoltaic-thermal system consisting of a linear solar concentrator and tubular absorber, Energy Conversion and Management (In Press, 1986).
7. Analytical performance evaluation of combined photovoltaic-thermal concentrator receiver systems with linear absorbers (In Press 1987).
8. Practical design considerations of a linear Fresnel reflector with a rectangular absorber illuminated on both sides (Communicated).
9. Optimum concentration ratio for a combined photovoltaic-thermal concentrator-receiver system (In Press 1987).
10. Optimum concentration ratio for an actively cooled solar concentrator-photovoltaic system with fin type absorber (In Press 1987).

<u>Conferences</u> :

1. Economic evaluation of concentrator-photovoltaic systems, presented at Int. Conf. on Physics and Energy for Development, Dhaka (Bangladesh) (1985).
2. On the economics of concentrator-photovoltaic systems, Proc. Recent Trend in Electrical Engineering, IIT Delhi (India) (1986).

C O N T E N T S

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