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Solar Thermoelectric System for Small Scale Power Generation

by

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Doctoral Thesis

Submitted in partial fulfillment of the requirement for the award of
Doctor of Philosophy
of Loughborough University

May, 1997

Abstract

This thesis is concerned with the design and evaluation of a small scale solar-thermoelectric power generation system. The system is intended for electricity generation and thermal energy supply to small scale applications in developing countries of the sunny equatorial regions. Detailed design methodologies and evaluations of both the thermoelectric device and the solar energy collector, which are parts of the combined system, are presented.

In addition to experimental evaluations, three theoretical models are presented which allow the design and evaluation of both the thermoelectric module and the solar energy collector. One of the models (a unified thermoelectric device model) concerns the geometrical optimization and performance prediction of a thermoelectric module in power generation mode. The model is unified in the sense that it accounts for the effect of all the parameters that contribute to the performance of the thermoelectric module, a number of which are ignored by the available design models. The unified model is used for a comparative evaluation of five thermoelectric modules. One of these is commercially available and the others are assumed to have optimum geometry but with different design parameters (thermal and electrical contact layer properties). The model has been validated using data from an experimental investigation undertaken to evaluate the commercial thermoelectric module in power generation mode. Results showed that though the commercially available thermoelectric cooling devices can be used for electricity generation, it is appropriate to have modules optimized specifically for power generation, and to improve the contact layers of thermoelement accordingly. Attempts have also been made to produce and evaluate thermoelectric materials using a simple melt-quenching technique which produces materials with properties similar to those of the more expensive crystalline materials.

The remaining two models presented here have been developed for the design and evaluation of solar concentrating system designed specifically for providing a suitably high temperature gradient across the thermoelectric device.

A detailed design methodology has been given for a two stage solar concentrator comprising a primary parabolic trough concentrator (PTC) and a secondary compound parabolic concentrator (CPC), a combination which makes use of the compactness of the PTC and the maximum concentration efficiency of the CPC. Different techniques for performance evaluation have been used which cover the range of operational conditions that the collector system may experience from fully evacuated, in order to suppress heat losses, to a collector at atmospheric pressure. The former is evaluated using a specifically developed analytical model which can predict solar energy collector performance under particular operational conditions. The model has been validated using experimental data. The thermodynamically more complex unevacuated operation, is modeled numerically (i.e. using computational fluid dynamics). With this approach the temperature distribution and flow field inside the solar energy receiver can be directly calculated.

An experimental prototype has been constructed and tested, and the results have been used to validate the analytical model. Results from the evaluation show that the system perform well at tilt angles up to about 30 degrees, which is well suited to the latitudes of regions for which the system is intended. The design is also found to be tolerable to the incoming sun rays to an extend that permits tracking adjustment to be made once every 15 to 20 days.

An economic analysis has been completed which shows that, a solar thermoelectric generation system can be cost effective source of energy, when compared to the existing alternatives.