THE ANU 20kW PV/TROUGH CONCENTRATOR

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ABSTRACT

This paper will describe the photovoltaic concentrator system being built with support from the Australian National University, Solahart Industries, Western Power, the Australian Greenhouse Office, Australian CRC for Renewable Energy and the Alternative Energy Development Board of Western Australia. The system has a generation capacity of 20kW. It comprises foundations, mirrors & supports, two axis tracking, and the aluminium passive heat sink receiver with solar cells mounted on the under surface. At the time of writing works are being commissioned with each of the component suppliers.

INTRODUCTION

The ANU has been actively engaged in the development of PV concentrator technology since 1995. One aim of the development process has been to prove the viability of the concept. To date there has been three systems constructed by the ANU to test the capability of components under development. These have ranged in collection area from $2.5m^2$ to $23m^2$ (nominal).

Having gained experience and confidence with these smaller systems the ANU has designed the prototype of a system which promises commercial viability. The latest system to be constructed in Perth WA will have a power generation capacity of 20kW from a total collection area of 154 m^2. Installation of the array will be carried out by Solahart Industries, exclusive licensee of ANU PV/Trough technology.

RATIONALE

Conventional PV solar powered systems generate electricity at a cost of $0.40 kWh or more. Costs must be reduced in order for the photovoltaic industry to expand further into the diesel fuel replacement, export and water pumping markets. The cost base for conventional PV technology is driven mainly by the cost of silicon wafers. This leads to a need to decouple PV systems from dependence on large numbers of silicon wafers if costs are to be reduced. It also means that the silicon in use must be used very efficiently.

Concentrator systems have the potential to greatly reduce the cost of photovoltaic power by using a large area optical system to focus sunlight onto a much smaller area of cells. In principle most of the expensive cell area is replaced by a cheap focusing system. A PV/Trough system, such as is being developed at ANU, consists of a parabolic reflective trough, concentrating light onto a line of cells (see fig 1). The few remaining solar cells in the system (at the focal line of the trough) are a relatively small part of total system cost. Thus expensive but efficient cells can be used without economic penalty.

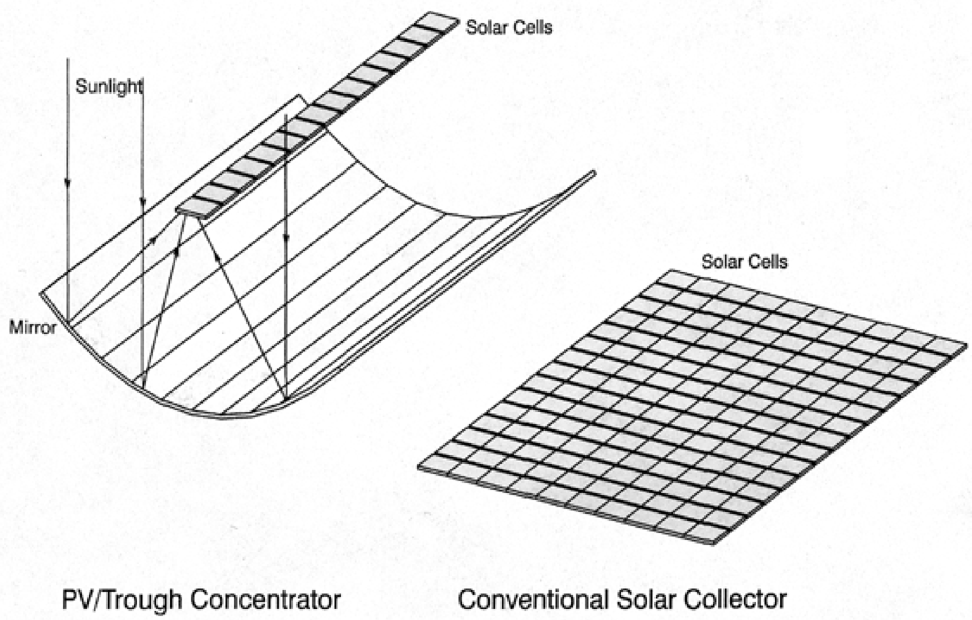

Fig 1: *Cell use in Trough Concentrator and Flat plate systems*

In addition to being cheaper per unit area, the power output of the PV/Trough system is larger than a flat plate system of an area equal to that of the mirror. In an economic feasibility study by the ANU in 1994 of the energy cost for diesel fuel saving, the PV/Trough system was estimated to produce electricity for about 60%of the flat plate cost at the time. Current analysis indicates that the PV/Trough can produce electricity for about $0.20 kWh if appropriate manufacturing economies of scale are achieved. This is more than half of the cost for electricity from an equivalent flat plate system.

ANU CONCENTRATOR SYSTEM HISTORY

The ANU Development Process

The ANU has demonstrated the viability of the PV/Trough technology by constructing three prototype systems. The research effort applied to prototype systems has allowed for testing, development and integration of various systems components.

To date the systems are

1995 $2.5m^2$ capable of 350W located at the ANU Dept. of Engineering building.
1997 $23m^2_{(nom)}$ capable of $3.5kW_{(nom)}$ located at Spring Valley (ACT)
1998 $3.8m^2$ capable of 400W located at Fremantle WA.

All systems feature two axis microprocessor controlled tracking, ANU solar cells, mirror concepts originated by ANU and receiver technology developed by ANU.

20kW PV/TROUGH ARRAY

The latest development of ANU PV/Trough technology is the 20kW system to be installed in Perth WA. The design is based upon the configuration of the Spring Valley array which would in effect act as the central bays for the 10 bay row. The 20kW array consists of 80 trough modules. Each trough module consists of a parabolic mirror, a receiver/heat sink with solar cells and associated supports. A diagram of the system is shown in figure 2. This demonstration array will form the basis for commercialisation of ANU PV/Trough technology, act as a test bed for all system components and provide a means of evaluation for interested parties.

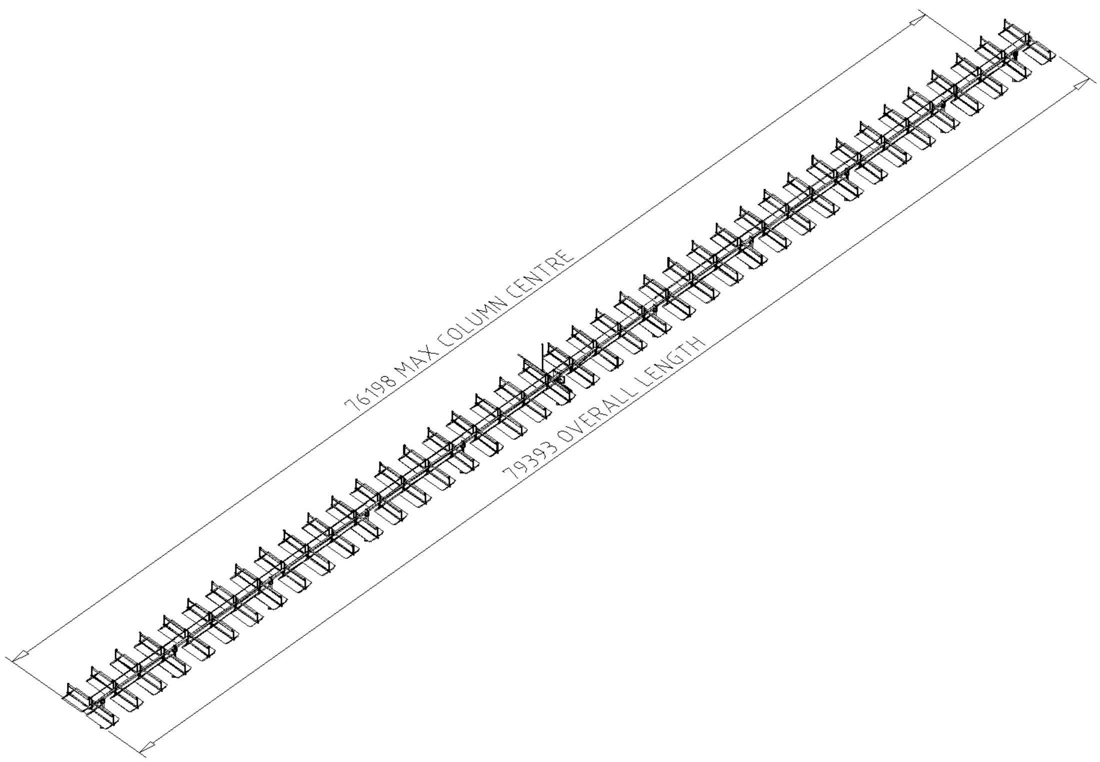

Fig 2: *20kW ANU PV/Trough System*

From the start of the project the ANU has maintained an awareness of the functional requirements for the system and have included many features into the design. The 20kW array will be connected directly to the grid thus avoiding the need for an energy storage system. Receivers provide a high current of about 12 amps per trough. Anticipating a harsh service environment the system is designed for a long service life with a minimum of maintenance.

With the exception of the tracking controller all PV/trough components have been sourced from Australian companies. With a minimum of investment Australian companies can adapt existing manufacturing processes to produce 95% of the total value of the system. There is also a great potential for export of the system and some of its sub-components for use by other manufacturers.

Support structure

The geometry of the support structure of the 20kW system features the widespread use of standard steel sections and has been optimised with a view to limiting the mass of material used. The distributed mass for the support structure is approximately 36.4 kg/m^2.

As the system will have to be transported by road each component is designed so that it may be packed flat. The structure is designed to be assembled on site and assembly of the whole structure may be achieved by a small crew using a truck mounted crane.

The foundation is a cast in-situ pier which offers low cost, ease of installation and flexibility in sizing. This design is very compatible with the methodology used by utilities for the installation of poles.

Mirrors

Mirrors for the 20kW array are a laminated glass structure of parabolic profile which encapsulates a silver mirror film. The overall dimensions are 1600mm long by about 1200mm wide.

Physical characteristics of this mirror design are:-
1. Impact resistance: sufficient to withstand hail damage, handling and transport.
2. Abrasion resistance: sufficient to withstand sand blast in dust storms and cleaning.
3. Rigidity: sufficient to withstand large wind loads.
4. Corrosion resistance: sufficient to ensure a long life.

Receiver

ANU solar cells are mounted directly to the receiver which also provides a cooling mechanism via an integrated passive heat sink. ANU solar cells are assembled into a cell package by adding tabs and a bypass diode. The cell packages are bonded to the receiver and joined in series by interconnecting cell tabs. Once assembled the cell string is encapsulated to exclude moisture and covered with glass for protection.

PV cells work at an optimal level when kept cool. A concentrator system can cause cells to run hot as a great amount of sunlight is directed to the cell. Passive cooling has been developed for this array which exhibits great reliability and low maintenance. This convective cooling system uses a finned aluminium unit.

The receiver has a distributed mass of 4.2 kg/m^2 but has not as yet been optimised. It can ultimately be reduced to 2.4kg/m^2 through the combination of providing thinner fins and using a wider mirror.

Solar Cells

A remarkably simple fabrication technique for high performance concentrator silicon solar cells has been devised. A total of 2,500 cells of area 20 cm^2 are being fabricated at ANU on 100mm wafers for the 20 kW project. The minimum acceptable efficiency is 20%, but the average cell efficiency is close to 22% at 20-30 suns. Typical parameters at 30 suns are an open circuit voltage of 760 mV, a fill factor of 0.78 and a short circuit current of 12 amps.

Significant cell production began in July. Month by month there are improvements in the yields of 20%+ efficient cells and cell production rates. The indicative cell cost of 22% efficient cells decreases each month. The cost goals for the end of the years 2000 and 2001 are $21/cell and $11/cell respectively, and these seem to be achievable.

The approximate breakdown of cell costs in September is:

labour (both direct and indirect)	60%
equipment depreciation	25%
direct wafer consumables	10%
other costs	5%

Additional equipment is being introduced to reduce labour requirements. Where possible the equipment is second hand. When the integrated circuit industry moves to a larger wafer diameter its production equipment becomes available at 10-20% of new price. Much of this equipment is in very good condition. Equipment includes a vacuum evaporator with planetary motion to allow many cells to be coated simultaneously; a cassette to cassette photoresist track coater; a cassette to cassette automatic mask aligner; a cassette spin rinser/dryer; a laser workstation for wafer dicing; and an upgraded electrolytic plating system.

A novel flash tester has been constructed for cell measurement. A reliable measurement can be made of a cell's complete current voltage characteristics at five to ten different light intensities over a decade range in a few seconds. The complete measurement, including mounting and dismounting of the cell, takes about 30 seconds. The system automatically computes and displays all of the important cell parameters.

An important aspect of cell fabrication is environmental testing to ensure cell performance stability. Accelerated life testing of the cells is being carried out for humidity and UV resistance, air-aging at elevated temperatures, temperature cycling and salt spray resistance. Similar tests are being performed on finished receivers.

Array Tracking

The 20kW system features two axis continuous tracking. All trough modules are mechanically linked so that one motor actuates the tilt and another actuates the roll. Both motors are controlled by a time based open loop central processing controller via a motor driver interface and position feedback system.

Description	Data
Mirror Aperture	1200mmx1600mm
Number of Mirrors	80
Total Reflector Area	154 m^2
Concentration Factor (Geometric) (Actual)	30:1 22:1
Cell Efficiency	22% under concentration
Power Output per Trough Module	250 Watts(peak) (SOC)
Power Output of System	20kW
Tracking Mechanism	2 Axis (accurate to within 0.5^{o})
Total System Efficiency	13%

Table 1: System performance for 20kW array (SOC: DB:900W/m^2 Amb:20^{o}C Wind:1m/s)

The Commercial Partners

The 20kW array project is being implemented by the ANU in partnership with Solahart Industries, Western Power and ANUTECH who has project management responsibility. The project will facilitate technology transfer from ANU to Solahart who is exclusive licensee of the technology. Western Power will benefit from gaining experience in operating a novel generation technology which may have considerable importance in diesel fuel saving over the next 5 years.

Close to half the funding for the project has been provided by the Australian Greenhouse Office Renewable Energy Investment Program, which was established to assist in the commercialisation of Australian renewable energy technology. Financial backing has also been provided by the Australian CRC for Renewable Energy and the Alternative Energy Development Board of Western Australia.

CONCLUSION

The ANU PV/Trough technology has been developed on functional systems intended for specific purposes. A pragmatic approach has been taken to the development process with a view to creating a commercially viable system. Along the way many bugs have been ironed out, the design has been partially optimised in terms of cost and manufacturability and some unique solutions have been derived.

The ANU PV/Trough project has passed beyond the development stage and is in its commercialisation phase. All suitable technology has been identified and a supply base has been established. The demonstration array is under development and will be completed later this year. The cost of most components have been investigated and appear to be within the estimates of the feasibility study. Economic analysis shows that the PV/Trough project can produce electricity for $0.20 kWh if appropriate manufacturing economies of scale are achieved. There is an awareness that demand already exists in Australia for this type of technology. The next step will be for Solahart to take the technology to full commercialisation.

ACKNOWLEDGMENTS

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