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PHOTOVOLTAICS AT ANU

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ABSTRACT: Copy WREN ABSTRACT. Concentrator Systems are an attractive means whereby the cost of PV electricity can be reduced. In a PV/Trough concentrator system most of the solar cells are replaced by a mirror, which costs far less. The few remaining solar cells in the system (at the focal line of the trough) are a relatively small part of total system cost. This means that expensive but efficient cells can be used without economic penalty. A linear parabolic PV concentrator has been developed at the Australian National University in conjunction with several companies, notably Solahart Industries. The system incorporates 2 axis tracking and either water or air cooled receivers. High efficiency ANU concentrator cells have been installed and are working satisfactorily.

1. INTRODUCTION

PV systems generate electricity for 40 to 100 c/kWh. Substantial cost reductions are required in order to compete with conventional electricity generation systems. The cost of PV energy is substantially driven by the cost of silicon wafers. One way of reducing cell costs is to use concentrator systems. Concentrators virtually eliminate wafer cost by replacing most of the solar cells with mirror or plastic lens, which have an area cost of around one fifth that of silicon solar cells. The few remaining cells can be expensive high efficiency devices without unduly increasing system capital costs. Another way of reducing cell costs is to reduce the cost of the silicon wafers. Thin crystalline silicon solar cells are a very promising way of accomplishing this.

Another major cost factor is balance of systems (BOS) costs, such as transport of materials to site, land, land preparation, foundations, support structures, interconnect cabling, inversion, transformation and labour. BOS costs will decline less quickly than solar cell costs since they arise from mature industries. Highly efficient systems have lower BOS costs because fewer modules need be installed for a given system output. It is clear that a system efficiency above 10%, and preferably above 15%, will be required for economical large scale PV.

This paper describes work in progress at ANU in two areas: a Photovoltaic/Trough concentrator system and a thin crystalline silicon solar cell technology called Epilift. Both of these technologies have substantially reduced silicon wafer costs and both are inherently high efficiency systems.

2. MARKETS

PV module shipments have grown from roughly 4 MWp in 1980 to 122 MWp in 1997, a growth rate of 20% per year [1,2]. This growth has led to an installed base of PV electricity generation capacity of greater than 600 MWp worldwide. Based primarily on the market for cost-effective off-grid applications, this growth is likely to continue at a rate of around 20% per annum over the next 15 years with potential annual module shipments of around 1,600 MWp in the year 2010. At wholesale module prices of $2/Wp, PV module manufacturer sales should be above $3 billion per year by the year 2010. BOS component sales and installation costs will be important components of the PV industry.

The success of worldwide PV industry to date can be attributed to government support. The dominance of the U.S., Japan and Germany in the development of PV technology and markets is, in large part, due to the relatively sustained government support provided in Japan (US$140 million/year), US (average US$65 million/year) and Germany (US$50-60 million/year). Government support to the manufacturing industry has been critical. These initiatives have brought the wholesale price of PV modules down from $100/Wp in 1970 to present prices of US$4/Wp on the market today.

Grid-connected PV systems are clearly not cost-effective today and are only projected to approach economic viability for distributed generation applications after the year 2007. Special markets created for "greenhouse friendly" technologies are likely to be dominated in many places by wind energy for the next decade at least. Off-grid markets in industrialized countries are expected to continue to increase. However, off-grid markets in developing countries will grow much more rapidly, particularly for rural electrification and telecom projects to provide basic electric power to the 2 billion people who do not have access to central electric grids.

Crystalline silicon (ie single and polycrystalline silicon) PV modules represent more than 86% of the commercial PV module technologies purchased today. Crystalline silicon technologies are continually being improved with present conversion efficiencies of 12% to 15% for most commercial PV modules. Transfer of technological improvements from the R&D labs to the manufacturing sector is expected to yield efficiencies of 15% to 22% by the year 2010. As the industry automates its production plants and reduces its material costs, wholesale module prices will likely decrease to the $2/Wp range by 2010.

It is likely to prove difficult for the non c-Si technologies to replace c-Si as the dominant substrate. Reasons include: present market dominance; silicon non-toxicity; silicon abundance; silicon cell efficiency advantage; silicon cell performance stability; the ability to use c-Si in a thin film form with the potential both for reduced costs and increased cell efficiency; the ability to use c-Si in both concentrating and non-concentrating applications; and the ability to borrow technology, people, raw materials and infrastructure from the integrated circuit industry.

Australia has an attractive near term market for the supply of PV systems in remote areas. The national grid only extends to 25% of the land surface. Although the interior is sparely populated, there are market opportunities for the displacement of diesel fuel in outback mining facilities, aboriginal settlements and townships [3]. In addition, large potential markets in Asia are located to the near north. Both concentrators and flat plate panels can enter this market. Unfortunately the Australian PV Industry has been hampered by erratic government policies, particularly in relation to market development and R&D support. R&D support has effectively been abolished except for near-commercial projects, leading to the demise of nearly all PV (and other solar energy) research groups.

However, the vibrant natural market in Australia has allowed the country to sustain two manufacturers (BP Solar and Solarex). The most promising Federal initiative is to mandate that 2% of electricity will come from renewable energy sources by 2010. Provided that milestones are set in the intervening years this will be a powerful market incentive. Several state governments, in particular New South Wales and Western Australia, have supported renewables in recent years.

2. PV/TROUGH CONCENTRATOR SYSTEM

Tracking increases annual energy output by 30% yet costs less than 30% extra to implement. This suggests that many large-scale central generation PV systems will be tracking systems, whether or not they are concentrating systems. In this scenario concentrating systems will have excellent prospects. Present markets are dominated by the requirement for small-scale maintenance free systems, which is why concentrators presently have no market. Concentrators must await the development of a market for large-scale central generation of PV electricity. Roof mounted systems, of course, will probably neither track nor concentrate.

The ANU has been working on a PV/Trough system since 1995. Early work provided a proof of concept system comprising of a single 2.5 m^2 trough. The system has an optical efficiency of 73%, a 19% cell efficiency (hence a receiver efficiency of 18%) and a system efficiency of 14% at Standard Temperature and Conditions (AM1D, 25^{o}C). The next step was the construction of a 12 mirror, 23 m^2 system at Spring Valley near ANU [4]. Each trough consists of a parabolic mirror, a receiver/heat sink, solar cells and associated supports. The system has a two axis - tilt/roll - tracking mechanism and a capacity of 2.8kW_{peak}.

The demonstration array comprises two bays. Each bay has a central support beam. In bay 1 the central beam supports three trunnion pairs on which a pair of the troughs rotate. Each beam is provided with a bearing support at each end and supported by two end columns and a centre column. The centre column incorporates the tilt mechanism, essentially a trolley in track arrangement. A semi-circular pulley is connected to the beams and the tilt trolley via two cables. As the tilt trolley translates it induces rotation of the beams through the cables and pulley, giving the system a tilt capability. Translation of the trolley is induced by a linear actuator powered by a DC motor. Each trough pair has a roll arm fitted and is connected to a common roll bar via a hinged pivot. The roll bar is induced to translate by a linear actuator powered by a DC motor. As the roll bar translates is causes the trough pairs to rotate via the hinged pivot. Each of the three columns is secured by a reinforced concrete pier foundation. Both motors are controlled by a time based open loop central processing controller via a motor driver interface and position feedback system. The controller and motors are powered by two lead-acid batteries with PV recharge.

PV cells work at an optimal level when kept cool. However a concentrator system can cause cells to run hot as a great amount of sunlight is directed onto the cell. For this reason both water cooling (active) and air cooling (passive) systems are being investigated. Active cooling is attractive where there is a local requirement for generating low grade heat. Passive cooling is preferred as it exhibits much greater reliability and zero maintenance. A low cost passive heatsink based on aluminium fins has been developed.

The mirrors are laminated like a car windscreen making them both impact and abrasion resistant and the support structure can withstand cyclonic conditions. A new type of mirror with a much lower potential cost is under development at ANU. As the system will have to be transported by road into remote areas 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 two-person crew using a truck mounted crane.

ANU is producing silicon concentrator cells on 100 mm wafers. These are high performance cells with phosphorus and boron diffused regions, silicon dioxide surface passivation and silver electroplated front and rear metal contacts. A rather elegant design has been developed which requires only a single non-aligned photolithographic step, no laser processing and (probably) no vacuum processing. Open circuit voltages and fill factors of around 750 mV and 0.79 respectively are observed at 30 suns concentration on 20 cm^2 cells. After the addition of an antireflection coating (an APCVD system is on order) efficiencies are expected to reach about 22-23% at 30 suns concentration.

The Spring Valley system is designed as a component of a modular system. It is the central two bays of a 12 bay row. Rows can be duplicated to form a field. By using a modular concept the system can be built up to match increases in demand or can be moved to a new location. These are important considerations in developing regions of the country

A 20 kW, 80 mirror system is under construction at Murdoch University in Perth in Western Australia with funding from the Renewable Energy Industry Program, Western Power and Solahart. It is anticipated that this system will be completed in mid 1999. This system will be similar to the Spring Valley system, with refinements.

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