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Recent Progress and Future Potential for Concentrating Photovoltaic Power Systems

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Recent Progress and Future Potential for Concentrating Photovoltaic Power Systems

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Introduction

The World Renewable Energy Congress focuses on how renewable energy can play an increasing role in the global energy mix as we move into the 21st century. So far, the contribution of photovoltaic (PV) power has been inconsequential in this mix. However, 2004 may mark a milestone as PV module production is predicted to top 1 GW/year for the first time. Thus, starting in 2004, we expect that each year the world will add the equivalent of one new 1-GW PV power plant. Although this is still a tiny fraction of the world's electricity generating capacity, this milestone provides a glimpse of a new vista: the possibility that PV power can provide electricity at a utility scale.

In the 1990s, sales of PV modules were dominated by small-size applications such as PV-powered water pumping, emergency telephones, and calculators. More recently, the dramatic growth in the PV industry has been fueled by rooftop systems, especially in Japan and Germany. Such subsidized, grid-connected PV systems are likely to drive PV markets in coming years. Distributed systems deliver power where it is needed, avoiding transmission losses; and residential and commercial systems can be financed along with the rest of a building. Japan and Germany continue to provide market incentives because of their belief in PV's long-term benefits.

As successful and important as the rooftop market is for PV sales today, the PV industry will be able to penetrate a larger fraction of the electricity market if PV systems are also used in larger installations, such as utility-owned systems, PV parks, customer-owned systems, and others. Because retail electricity costs more than wholesale electricity, it is often assumed that PV will address, with incentives, the retail market long before the wholesale market. Here, we show data suggesting that they can grow together.

Concentrating PV (CPV), which uses low-cost lenses or mirrors to focus sunlight on high-efficiency solar cells, has often been presented as a lower-cost approach to utility-scale PV power.[1] Although CPV typically does not compete in rooftop or other current PV markets, CPV could be a major player in a utility-scale market. It is the purpose of this paper to explore the potential of utility-scale PV power, and, specifically, the opportunity that may arise for CPV.

Current installations of utility-scale CPV systems

Worldwide, there are dozens of companies developing CPV products today. Over the years, a number of companies have installed 100-500-kW demonstration systems, but these companies have faced the difficult reality that a customer base for this style of system has been lacking.[1] Recently, two companies (Solar Systems, Pty. Ltd., of Melbourne, Australia, and Amonix, Inc., of Torrance, CA USA) have identified relatively stable markets for large CPV systems.

Solar Systems has developed a relatively mature CPV dish technology and has installed more than 200 kW in Central Australia (see Fig. 1). The Australian outback uses diesel for electricity production and distribution. The cost for electricity from these small grids is relatively high, and CPV provides a cost-competitive option for these markets. Solar Systems is currently building three more large systems (total of 750 kW) in Australia. They have established an independent power producer, Solar Power Stations Australia, who expects to be operating more than 4 MW of solar power stations by the end of 2005. They are contracting their next systems for $5.50/Wac, with annual electricity generation estimated at over 2700 kWh per installed kWac.

In the USA, Arizona's Environmental Portfolio Standard requires regulated electric utilities to generate 1.1% of their kWh energy sales from renewable resources by 2007. Of that, at least 60% is to be from solar. So far, Tucson Electric Power has installed about 5 MW of fixed (non-tracking), flat-plate PV systems; APS has installed about 5.5 MW of PV systems, including fixed and single-axis-tracking PV systems, and many new technologies, including over 570 kW of CPV systems made by Amonix (see Fig. 2). The cumulative electricity production of the CPV systems is shown in Fig. 3.

As PV technology begins to contribute electricity at a utility scale, it is increasingly useful to quantify PV's performance in kWh – the commodity used by a customer and delivered by a utility – rather than documenting only installed plant power ratings in kilowatts.

Figure 1. Photograph of field of Solar Systems' CS500 dishes on-sun in Australia.

Figure 2. Photograph of field of PV systems at APS' Prescott, AZ, facility. The three large (35-kW) CPV systems on the right are Amonix systems. The systems on the left are single-axis-tracking, flat-plate silicon systems.

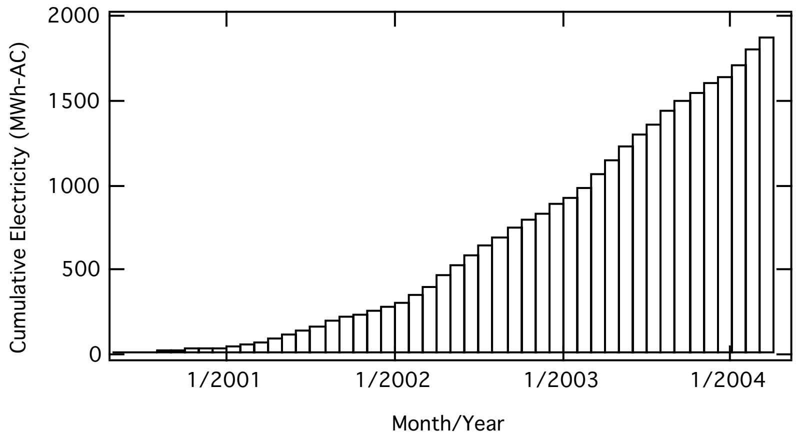

Figure 3. Electricity generated by Amonix/APS CPV systems. CPV systems use direct sunlight. The direct-beam solar resource for CPV is best in locations with clear skies such as found in the desert southwest of the USA and the Australian outback.

The actual energy productivity (or "yield") of various systems can be compared by normalizing the electricity generated by the rating of each system. The exact value depends on the site's design, solar resource, temperature and wind conditions, and system failures. In sunny climates, a PV system that tracks the sun is expected to generate more electricity than one that is fixed. Figure 4 shows actual solar plant productivity for a variety of APS systems in 2003, using AC ratings equal to 85% of the PV DC standard test conditions (STC) rating. For each kWac installed on single-axis trackers, between 2125 and 2360 kWh were generated in one year. Rooftop systems, by comparison, generated between 1210 and 1845 kWh/kWac per year. The lower performance of some of the rooftop systems is due to installation in a horizontal configuration, which is a non-optimal position for year-round sunlight. Solar resource data can be used to estimate the expected output for many orientations and sites in the USA.[2] In addition, however, the power output of rooftop systems may be compromised if the panels run hot because of poor ventilation from close contact with the roof or if the panels are shaded, e.g., by a nearby tree or building. Inverter and other failures also contributed to scatter in the data of Fig. 4. The observed performance of the developmental CPV systems is in between that of tracked and fixed flat-plate systems, and is improving as early prototypes are refined into mature CPV products. As expected, the utility systems have an advantage in terms of being able to capture more sunlight because of the way they are mounted.

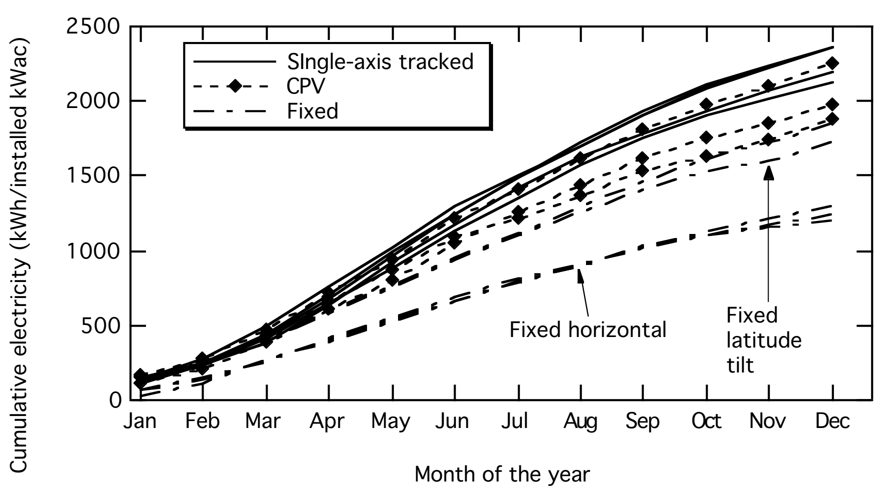

Figure 4. Electricity generation over the course of a year for single-axis tracked flat-plate, concentrator, and rooftop (fixed) systems sited in Arizona, quantified as kWh generated per kWac installed. The kW rating was determined from the DC electricity generated at 1000 W/m^2 for flat-plate or 850 W/m^2 for concentrator systems. The AC rating was assumed to be 85% of the DC STC rating.

Rooftop compared with utility approaches to large installations of PV

The retail price of electricity is about three times the wholesale price. Thus, it is frequently argued that PV will be able to compete in the retail electricity market long before its price is sufficiently reduced to compete in the wholesale market. However, the cost per watt of installing and operating retail systems is higher than the costs of similar utility systems because of the economies of scale. For this discussion, we will equate retail PV systems with rooftop systems and wholesale PV systems with tracked systems installed in large fields. Large, fixed systems should also be studied, but were not part of this study. There are some circumstances in which the installation costs of rooftop systems can be low, e.g., the case of a new, large housing project where the builder might choose to integrate and install many identical PV systems at the time of construction. But, in general, there are added costs and performance penalties associated with rooftop systems; especially for retrofits, there can be permit, structural, architectural, and electrical issues. There are very few studies available that objectively quantify the difference in the costs of installing and operating retail and wholesale systems. Here we summarize in Figs. 4 and 5 a comparison of rooftop and field systems that APS installed.

In figure 5, (a) shows the relative costs of APS' most recent rooftop and field systems; (b) compares kWh electricity output per installed kWac for the same set of systems; and (c) combines the first two datasets and shows that the field PV systems generated nearly twice as many kWh per dollar spent. Thus, given a fixed budget and the goal of generating as many kWh as possible, there is an advantage to using the field approach. The results also suggest that public support for market incentives would yield a higher rate of return for investment in incentives for utility markets. In practice, budgets depend on persuading customers to invest in green power, and the budget may be leveraged by, for example, market incentives for individuals' purchases of systems, incentives for utility purchases, or offering green electricity at a higher price. In the 1980s, market incentives were critical elements in bringing wind into large-scale utility projects that demonstrated their potential for further market penetration with and without future incentives.

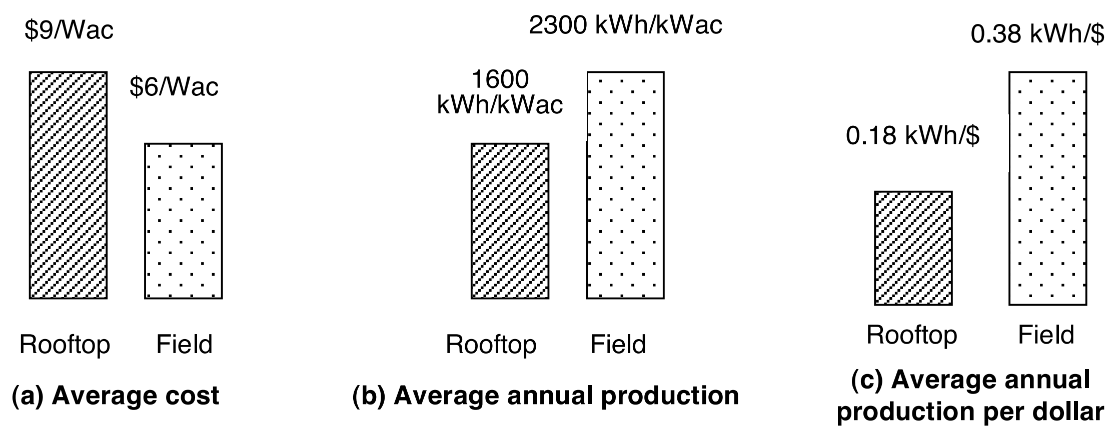

Figure 5. Comparison of flat-plate rooftop and field system costs and average annual production as found by APS for recent installations. The comparison is for similar flat-plate panels installed in a fixed geometry on rooftops or on one-axis trackers in fields. The kWh/$ metric depends on the solar resource available at the specific site. Other metrics, such as the levelized cost of electricity are also useful for comparing performance of systems. . The exciting conclusion is

that a PV technology that can compete in today's subsidized rooftop market may also compete in a similarly subsidized wholesale market.

The future for CPV

Once the PV industry has demonstrated that it can enter the utility-scale market, this larger market can be opened for CPV. CPV technology is less mature than flat-plate silicon PV, but is rapidly advancing both in the field, as shown above, and in the laboratory. Improvements in inverter reliability, tracking accuracy, and system design are improving performance in the field and lowering cost. APS' data shows that newer CPV systems in Arizona each year deliver about 0.3 kWh per dollar invested, and projects that this number will roughly double in high volume. Solar Systems is projecting annual production of 0.49 kWh/$ invested for their next systems.

One simple approach to reducing the cost per watt of a concentrator system is to replace the current 25% silicon concentrator cells with even more efficient concentrator PV cells. Assuming unchanged optics and solar cell costs, each increase in the cell efficiency reduces the cost per watt. The National Renewable Energy Laboratory is currently funding industry and university subcontracts under the High-Performance PV Project. The project's long-term goal is creating a prototype of a CPV system with a 33% efficiency using a 40%-efficient cell.[3] Spectrolab, of Sylmar, CA, has already reported a 37% efficiency using a GaInP/Ga(In)As/Ge three-junction concentrator cell.[4] Amonix, Solar Systems, and other concentrator companies are exploring the use of these higher efficiency cells to improve performance and reduce the cost per watt of their CPV systems. CPV still has substantial opportunity for improvement and will be an exciting technology to watch as the utility-scale PV market becomes a reality.

Summary

A comparison of the cost and performance of rooftop (retail) and field (wholesale) flat-plate PV systems in Arizona shows that the rooftop systems were more expensive, whereas the single-axis-tracking systems installed in large fields generated more electricity. The combined effect was that, in this case, the tracked PV systems generated twice as many kWh per dollar invested. This study inspires more detailed and geographically diverse studies and provides motivation to consider large-scale systems whenever the goal is to generate many kWh of solar electricity per invested dollar.

Concentrating PV is being used in both the USA and in Australia for large-scale systems. These systems are still evolving toward improved performance and will provide new technology options as utility-scale markets are identified. Incentives for these markets provided by public support for clean, home-grown energy technologies would accelerate their progress.

Acknowledgments

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