Analysis of Photovoltaic Concentrating Solar Energy Systems

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ABSTRACT

In this paper the photovoltaic concentrating solar energy systems are analyzed. Both the Fresnel lens light refraction and mirror light reflection concentrating optical systems are considered. The main parameters and properties of photovoltaic concentrating solar energy systems are outlined. It is shown that the multi-parameter cost optimization is necessary to conduct to reduce the cost of photovoltaic concentrating solar energy systems.

Keywords: PV Concentrator Analysis; Fresnel lens; Reflecting mirrors

1. INTRODUCTION

Many visionaries, entrepreneurs, researchers, businesspeople, environmentalists, and energy consumers have dreamed of a significant solar-energy future that will benefit the entire world. Solar photovoltaic (PV) generators are already an effective solution for supplying electric power in many applications: last year, almost 1.2 gigawatts (1000 megawatts = 1 gigawatt or 1 GW) were sold throughout the world—more electricity than the equivalent of one nuclear reactor. PV is a technology that has already demonstrated its effectiveness and holds great promise for electrical generation throughout the world [1-3].

The photovoltaic effect is the physical phenomenon that converts sunlight to electricity. The basic power element of a PV generator is the semiconductor solar cell, an electronic device typically made of refined silicon. Solar rays (photons) striking the solar cell, are directly transformed into electricity by solar cells. PV generators have many advantages: they are silent, non-polluting, require little maintenance, and can be installed close to the user, reducing the need for long transmission lines [4, 5].

Recently, PV solar generators have been expanding into distributed electrical generation markets around the world. Present trends indicate that there could be many tens of gigawatts of PV systems installed during the next 10-20 years [6].

The main problem with solar energy is efficiently collecting this energy and cost effectively converting it into electricity. Existing solar generating systems are still too expensive. Electricity from solar electric systems is more expensive than that produced by conventional electrical generation systems. For this reason, it is extremely important to create cost-effective solar electric systems.

Several paths are being explored that can reach the desired PV cost reduction (Fig. 1). The first path is to increase the solar energy-to-electricity conversion efficiency (curve #1), but refined silicon is expensive and there is a conversion limit. The second path (curve #2) is to use a thin-film, but still efficient, semiconductor material.

One of the most promising options is concentrator PV (curve #3). Many believe this option is the lowest-cost approach in the long term [7, 8] because most of the cost is for inexpensive mirrors or lenses that focus sunlight onto solar cells that are hundreds of times smaller than the area of the mirrors or lenses. It is also possible to incorporate the highest-efficiency solar cells into concentrator PV systems because the solar cell cost can be as low as 10% or less of the system cost. Note that the highest solar cell efficiency today is 37.9%, compared with the 10%-15% efficiency for most PV panels sold throughout the world today.

Photovoltaic Concentrating Solar Energy Systems

At present, several state governments in the southwest United States, as well as the governments of Australia and Spain, are funding the development of concentrator systems because they see the low-cost potential for this approach. Japan and Germany are also funding concentrator PV development because they understand its potential for export.

To concentrate solar energy, designers can use light refraction (using plastic Fresnel lenses) or light reflection (using mirrors). The plastic Fresnel lens can either be a circular lens producing a focused spot on a single cell, or a linear lens producing a focused line of sunlight on a row of cells. Amonix, a U.S. company in California, uses an array...
of point-focus Fresnel lenses (Fig. 2) [9-12]. Each lens focuses sunlight to an intensity of 250 suns onto a silicon cell.

Fraunhofer ISE (Freiburg, Germany) and Ioffe Institute (St. Petersburg, Russia) also use point-focus Fresnel lenses in their concentrator PV designs called FLATCON (Fresnel Lens All-glass Tandem cell CONCentrator) and FLASHCON (Fresnel Lens All-glass Silicon High efficiency cell CONCentrator) [13].

The U.S. Company ENTECH has developed line-focus Fresnel lens modules [7]. Each module uses rows of silicon cells operating at 20-suns concentration, in a design that ENTECH calls SolarRow. In principle, SolarRow and other concentrator PV designs can be scaled to multi-kW sizes for distributed generation and utility use. The Amonix 25-kW unit shown in Fig. 2 can be duplicated many times to produce power-plant capacities of 1 MW to 10 MW, to 100 MW or more. Amonix presently has about 600 kW of their systems installed by the utility Arizona Public Service, and they recently announced that a manufacturing plant will be constructed in Spain in fall 2005.

Besides the use of plastic lenses, it is also possible to use mirrors to concentrate sunlight. Solar Systems in Australia has developed a dish concentrator PV system and installed several hundred kW in central Australia to provide electricity in a diesel-based distributed generation system for aborigine villages [14]. Diesel fuel for the electricity generation systems costs $1/liter just for transportation, so the concentrator PV systems are cost effective in this application by reducing the amount of diesel fuel needed. The Solar Systems’ reflecting mirrors are made of thin glass sheets, silvered on their rear surfaces, and protected in shaped concave aluminum pans. The concentrator mirrors are mounted on a stable platform with a two-axis tracking system driven by mechanical actuators. This new dish concentrator produces 20 kW at 19% overall efficiency, using highly efficient SunPower solar cells from the United States.

EUCLIDES is the photovoltaic concentration technology developed by BP-Solarex, the PV division of BP-Amoco, in cooperation with the Institute of Solar Energy, which is the leading solar research arm of the Politechnical University of Madrid [15]. The EUCLIDES concentrating array consists of a reflecting parabolic trough tracking the sun around the horizontal axis. With its 84-m-long tracking 14 arrays, it reaches a 32x geometric concentration ratio designed for a peak power of 480 kW (Fig. 3).

A quick search on the Internet finds many other small companies around the world that are just beginning to develop their own designs for concentrating PV systems [16]. Only two companies, Amonix in the United States and Solar Systems in Australia, have spent over 15 years to develop their product designs. By comparison, all other concentrator PV designs are still in their research and development phases.

Except for low concentration ratios of less than 10 suns, all PV concentrator systems need to track the sun throughout the day and year to be effective. Under high solar-energy concentration, the operating temperature of cells increases. Cell efficiencies decrease as temperatures increase, so the solar cells cooling designs minimize solar-cell heating. Thus, solar tracking and solar-cell cooling designs do add to concentrator PV system costs. The average prices of power produced by existing PV concentrating systems are about 6 US$/watt. Note that the price of the above-mentioned EUCLIDES project is 5.53 US$/watt [17].

As mentioned above, concentration of sunlight reduces the high cost of photovoltaics by replacing large areas of expensive semiconductor solar cells with relatively inexpensive mirrors or lenses. When solar concentration increases, it becomes necessary to incorporate a cooling system or design for dissipating heat to reduce the temperature of solar cells. In this case the concentrator PV generator can become more complicated, less reliable, and expensive. Also, at high concentrations, tracking can become more expensive because it has to be more accurate. Thus, as a function of the concentration ratio, the cost of a prototype concentrator PV design is expected to decrease to a minimum and then increase at very high concentrations. It means that some optimum value of concentration is likely to occur for each concentrator PV design [18-26].

The cost of concentrator PV systems depends on the concentration ratio, but also on many other parameters such as the focal distance, length of linear concentrators.
forming an array, number of arrays, type and accuracy of tracking system, materials, installation. It also depends on the parameters of the solar cells used (efficiency, operating temperature, dimensions, and price). Concentrator PV structures must also survive winds and other environmental influences, specified for different regions, and these costs can be significant. Thus, a multi-parameter optimization is necessary to obtain the answers needed for a cost-effective concentrating PV system design.

2. SUMMARY

At present several companies have developed and installed the reliable PV concentrating solar energy systems. The price of the existing PV concentrating systems is high. To design the cost-effective concentrating PV systems it is necessary to realize the multi-parameter cost optimization of these systems.

REFERENCES

9. www.sunpowercorp.com/how_does_it_work.htm
14. www.edtekin.com/Products/Solar_Concentr.../EDTEK_SolarCon.htm