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Solar Power and PVs

Each day more solar energy falls to the earth than the total amount of energy the planet's approximately 6 billion inhabitants would consume in 26 years. While it's neither possible nor necessary to use more than a small portion of this energy, we've hardly begun to tap the potential of solar energy.

Although every location on earth receives sunlight, the amount received varies greatly depending on geographical location, time of day, season, and light. The southwestern United States is one of the world's best areas for sunlight. This desert region receives almost twice the sunlight of other regions of the country. Solar energy systems use either solar cells or some form of solar collector to generate electricity or heat for homes and buildings. The primary solar energy technologies for power generation are PVs and thermal systems.

PV devices use semiconductor material to directly convert sunlight into electricity. Solar cells have no moving parts. Power is produced when sunlight strikes the semiconductor material and creates an electric current. Solar cells are used to power remote homes, satellites, highway signs, water pumps, communication stations, navigation buoys, streetlights, and calculators (Fig. 2–1).

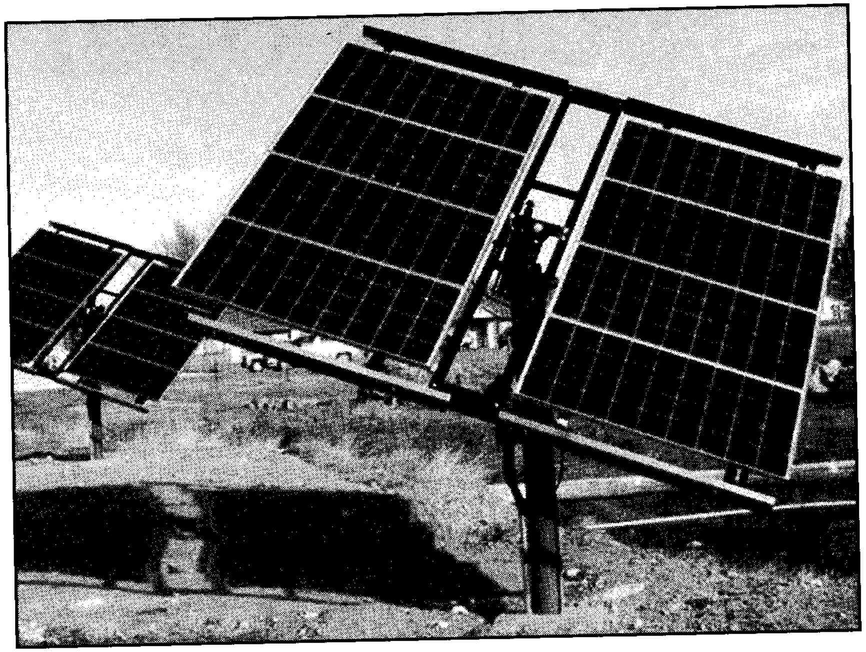

FIG. 2–1 A PV INSTALLATION NEAR HOT SPRINGS (COURTESY OF SHELL SOLAR)

PV

Solar thermal systems generate electricity with heat. Concentrating solar collectors use mirrors and lenses to concentrate and focus sunlight onto a receiver mounted at the system's focal point. The receiver absorbs and converts sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity.

Solar energy technologies offer a clean, renewable, and domestic energy source. The generating systems powered are also modular so they can be constructed to meet any size requirement and are easily enlarged to meet changing energy needs.

Solar energy technologies have made huge technological and cost improvements, but except for certain niche markets like remote power applications, they are still more expensive than traditional energy sources. Researchers continue to develop technologies that will make solar energy technologies more cost competitive.

Solar Basics

Solar cells convert sunlight directly into electricity using semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity.

This process of converting light (photons) to electricity (voltage) is called the PV effect.

Solar cells are typically combined into modules that hold about 40 cells, then about 10 of the modules are mounted in PV arrays that can measure up to several meters on a side.

These flat-plate PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. About 10 to 20 PV arrays can provide enough power for a household. For large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system.

Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Thin film technology has made it possible for solar cells to now double as rooftop shingles, roof tiles, building facades, or the glazing for skylights or atria. The solar cell version of such items as shingles offers the same protection and durability as ordinary asphalt shingles.

Some solar cells are designed to operate with concentrated sunlight. These cells are built into concentrating collectors that use a lens to focus the sunlight onto the cells. This approach has both advantages and disadvantages compared with flat-plate PV arrays. The main idea is to use very little of the expensive semiconducting PV material while collecting as much sunlight as possible. Because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the sunniest parts of the country. Some concentrating collectors are designed to be mounted on simple tracking devices, but most require sophisticated tracking devices, which further limit their use to electric utilities, industries, and large buildings.

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. Only sunlight of certain energies will work efficiently to create electricity, and much of it is reflected or absorbed by the material making up the cell.

Thus, a typical commercial solar cell has an efficiency of 15%—about one-sixth of the sunlight striking the cell generates electricity. Low efficiencies mean that larger arrays are needed, and that means higher cost. Improving solar cell efficiencies while holding down the cost per cell is an important goal of the PV industry, National Renewable Energy Laboratory (NREL) researchers, and other U.S. Department of Energy (DOE) laboratories, and they have made significant progress. The first solar cells, built in the 1950s, had efficiencies of less than 4%.

Concentrating solar power

Many power plants today use fossil fuels as a heat source to boil water. The steam from the boiling water rotates a turbine, which activates a generator producing electricity. However, a new generation of power plants, with concentrating solar power systems, uses the sun as a heat source. There are three main types of concentrating solar power systems—parabolic-trough, dish/engine, and power tower.

Parabolic-trough. Parabolic-trough systems concentrate the sun's energy through long rectangular, curved (U-shaped) mirrors. The mirrors are tilted toward the sun, focusing sunlight on a pipe that runs down the center of the trough. This heats the oil flowing through the pipe. The hot oil then is used to boil water in a conventional steam generator to produce electricity.

Dish/engine. A dish/engine system uses a mirrored dish (similar to a very large satellite dish). The dish-shaped surface collects and concentrates the sun's heat onto a receiver, which absorbs the heat and transfers it to fluid within the engine. The heat causes the fluid to expand against a piston or turbine to produce mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity.

Power tower. A power tower system uses a large field of mirrors to concentrate sunlight onto the top of a tower, where a receiver sits. This heats molten salt flowing through the receiver. The salt's heat is used to generate electricity through a conventional steam generator. Molten salt retains heat efficiently, so it can be stored for days before being converted into electricity. That means electricity can be produced on cloudy days or even several hours after sunset. There is a case study later in this chapter detailing the largest, most innovate power tower currently under construction in Australia.

Passive solar heating and daylighting

Step outside on a hot, sunny summer day, and you'll feel the power of solar heat and light. Today, many buildings are designed to take advantage of this natural resource through the use of passive solar heating and daylighting.

The south side of a building always receives the most sunlight. Therefore, buildings designed for passive solar heating usually have large, south-facing windows. Materials that absorb and store the sun's heat can

The main observations revealed in the EPRI study included the following:

Grid-connected PV. The most notable observation was the surprising amount of grid-connected activity because these systems are not yet cost-effective when compared to conventional grid power. According to EPRI, true economic viability for PV in comparison to utility systems will require PV system costs of less than $3000/kW. Most of the current PV systems were installed at three times that cost.

Nonenergy added value. People will pay a premium for PV for several reasons. Utilities can find distributed benefits by siting PV along a distribution feeder, saving the utility line losses. Systems with storage and power conditioning can boost power service reliability and power quality. Rooftop systems increase insulation and protection for the roof. Parking lot systems provide vehicle shade and weather protection.

Grid interconnection. The small PV systems currently in use don't cause significant technical problems for the utility grid. In some situations, the PV installations can benefit distribution companies through lowered line losses, peak reduction and deferral of upgrades to the distribution system.

Reliability. PV modules have proven reliable and durable, working well after many years in service. The two problem areas seen in older systems are inverter unreliability and output intermittency. Inverter problems can be mitigated by using more small inverters and by designing systems with backup inverters. EPRI is also studying to apply PV direct current (DC) immediately to grid-connected loads to avoid inverter problems. Output intermittency problems can be addressed by adding storage. As a general guideline, according to EPRI, PV can be up to 20% or 25% of load capacity without causing any problems.

Location. PV can be used anywhere in the United States. Systems in the Midwest and Northeast can be as beneficial as in the Southwest because the regional variation in sunlight, and therefore in PV energy cost, is smaller than the variation in retail electricity prices.

Strategies for funding. A number of strategies are being seen. Some utilities have started projects to field PV generation to supplement conventional power supplies. More than 90 utilities have introduced green-pricing programs, and in these programs PV is often the leading clean energy source. Some states and municipalities have established incentives for PV systems to promote PV's benefits. By utilizing green-pricing programs and optimizing the multiple values available through PV power, utilities can include PV projects without impacting their profitability.

Teaming. Most of the cases in the EPRI study were cooperative arrangements among utilities, customers, government agencies, and suppliers. The stakeholders recognized that they have a common goal in implementing renewable energy.

Affordability. Even though PV electricity may be more costly on an energy basis, there appears to be a market for it if the systems are affordable to consumers.

Increased production. PV manufacturers are boosting production to supply increasing demand, both domestic and international.

Types of Solar Cells

PV conversion, which enables the sun's rays to be converted into electricity, is based in solar cells manufactured from silicon. Silicon is one of the most abundant materials on the planet, in the form of quartz sand, and is an environmentally friendly material.

PV technology was pioneered in 1954, when Bell Lab scientists displayed the first silicon solar cell at the National Academy of Science in Washington, D.C. The cell contained specially treated silicon strips which, when exposed to light, powered an FM radio. The *New York Times* hailed the new technology, proclaiming *Vast Power of the Sun is Tapped by Battery Using Sand Ingredient.*

The silicon solar battery was thought to *mark the beginning of a new era, leading to the realization of one of mankind's most cherished dreams - the harnessing of the almost limitless energy of the sun for the uses of civilization.*

The *Times* may have overstated things a bit, since PV is still a niche technology, due primarily to the expense of the equipment.

A number of laboratories and manufacturers are working hard to improve generation while decreasing costs, which has lead to a number of technologies and approaches to PV.

Solar cells can be made from a variety of semiconductor materials. Also, each cell has an electrical contact with the semiconductor that carries the electrons away from the cell and into the electrical circuit where they can put their energy to use, lighting light bulbs or charging batteries.

The whole cell is encapsulated in a transparent cover providing environmental protection and containing an anti-reflection coating to make sure that as little light as possible is reflected away from the cells.

The different types of solar cells are:

- crystalline silicon
- thin film
- nonsilicon compound thin film
- nano-crystalline
- fullerene

Case Study: Sant
Boasts Biggest Roo

Almost three acres of the Santa Rit
California are covered with PV solar collecto
kW array to 1.18 MW and making the fac
installation in the United States.

PowerLight Corp. of Berkeley, Californi
on the jail during the summer of 2001. The
that PowerLight was commissioned to increase
The combined project has reduced the facili
grid-generated power by 35%. More than 2.5
from California's grid by the Santa Rita proj
the state's consumers by reducing grid pow
occur during peak electrical demand hou
transmission lines are the most constrained.

Based on local electricity rates, the total
total about $425,000 in the first year of ope
savings projected over the 25-year life of the

Differentiating solar radiation types

Sunlight arrives at earth in three different ways. They are collectively referred to as global radiation. The three types follow:

- *Direct radiation.* When sunlight travels from the sun to the ground with only a slight scattering of the sun's rays in the atmosphere. At any time of year, about 80% of the Sahara desert's total solar radiation is from direct sunlight.
- *Diffuse radiation.* When sunlight is scattered by clouds or haze. In Northern Europe, the proportion of diffuse light can be up to 80% of the total solar radiation in winter and up to 50% in the summer.
- *Albedo radiation.* When sunlight is reflected from the ground. For example, white surfaces such as snow reflect the sun's rays and stay cold. In contrast, dark surfaces absorb solar energy and become warm.

Solar factoids

Earth receives as much energy from sunlight in 20 days as is believed to be stored in its entire reserves of coal, oil, and natural gas.

Some 2,000 years ago the Greeks used mirrors to focus the sun's rays on Roman ships, causing them to catch fire.

There are three main types of solar power systems: solar buildings, solar thermal concentration systems, and PV cells.

The term PV comes from the Greek *phos*, which means light and *volt*, from the scientist Alessandro Volta. In other words, PV literally means *light-electricity*.

With today's technology, houses with passive solar design and efficient insulation can save as much as 99% of energy used for space heating and cooling.

Although the sun releases 95% of its energy as visible light, it also produces infrared and ultraviolet rays.

Each part of the solar spectrum is associated with a different energy. Within the visible portion of the solar spectrum, for example, red light is at the low-energy end and violet light is at the high-energy end, with 50% more energy than red light. *(Courtesy of DOE and Shell Solar)*