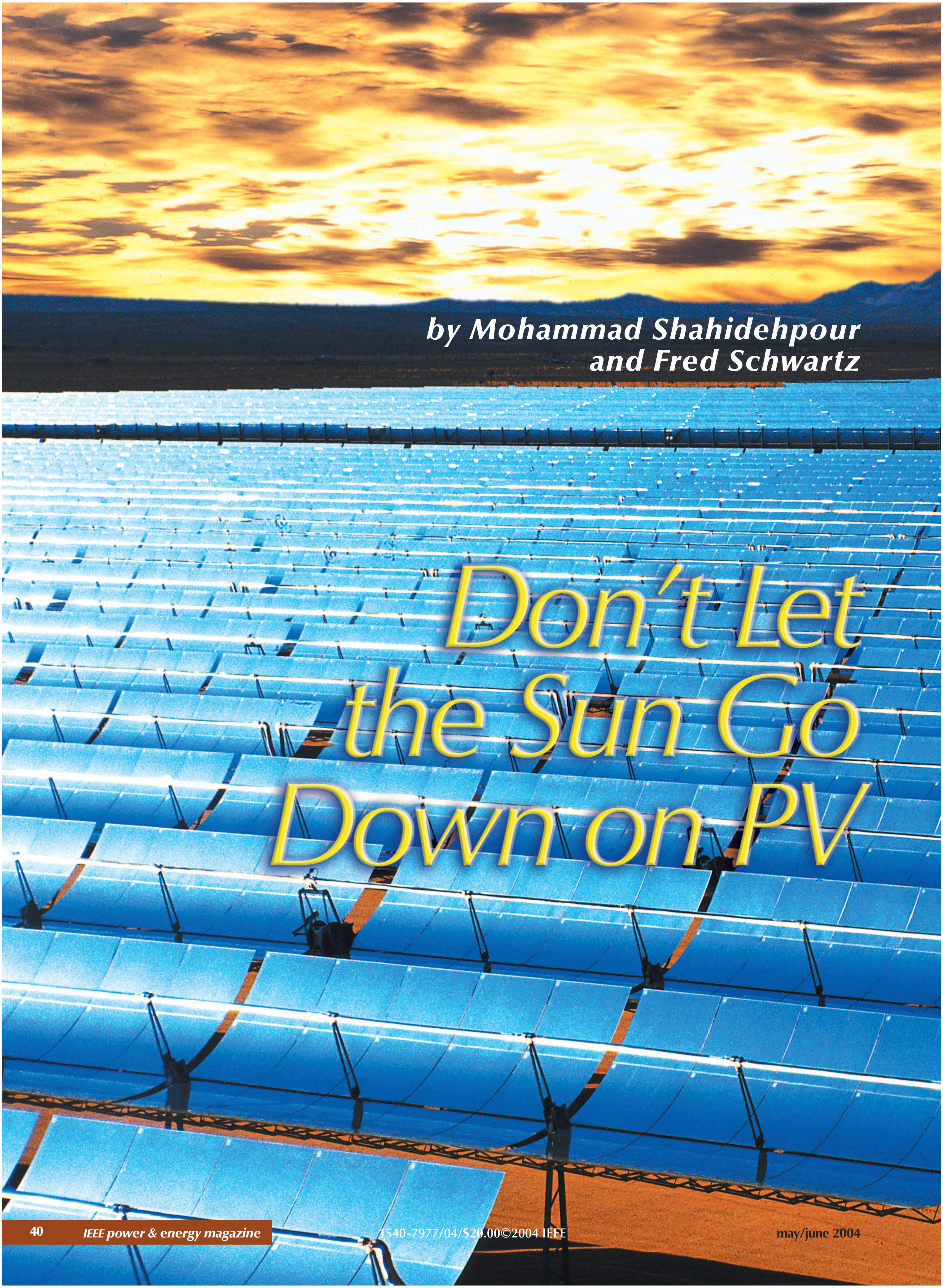

by Mohammad Shahidehpour
and Fred Schwartz

Don't Let the Sun Go Down on PV

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The Challenges of Photovoltaics in Restructured Power Systems

THE U.S. ECONOMY RUNS PRIMARILY ON FOSSIL FUELS, WHICH ARE WIDELY recognized as a major cause of environmental destruction both in terms of depletion of natural resources and pollution. U.S. energy demand is projected to rise to 127 quadrillion Btus by 2020, even with significantly improved energy efficiency. However, the domestic production of fossil energy is expected to rise to only 86 quadrillion Btus by 2020. The shortfall in the United States between projected energy supply and demand in 2020 is nearly 50%, while the United States is the third-largest oil producing nation in the world. At the same time, a number of factors will make it difficult to increase the fossil energy production in response to the growing demand for energy. These factors include limitations on access to federal lands with high potential for new discoveries, infrastructure constraints such as electricity transmission and gas pipeline bottlenecks, and conflicts with legitimate land use and environmental and other public policy goals.

In response to global issues for the generation and delivery of electrical power, photovoltaic (PV) and other renewable energy technologies are gaining acceptance as a way of maintaining and improving living standards without harming the environment. Figure 1 shows that during the last decade, renewables have contributed remarkably to U.S. energy production outpacing all fuel sources except nuclear (see National Energy Policy in "For Further Reading"). Unlike other distributed electricity generation alternatives such as fuel cells and microturbines, PV enables 100% renewable, zero-emission electricity production that is modular, scalable, and completely hedged against future fossil fuel price hikes. PV could help mitigate energy crises by reducing peak demand and securing the delivery of power in congested locations by decentralizing the power generation.

Many PV arrays are designed as stand-alone systems that are equipped with batteries to store electricity for sunless hours and operate completely independent of the grid. However, grid-connected PV, in which PV backs up or supplements the grid power, represents the fastest growing market segment today, already comprising about 40% of current PV sales according to the industry statistics.

As the PV industry continues to grow, and for that growth to be sustainable, PV systems will need to become less costly and more reliable. It is further clear that public and private support for the PV research and development is required to enhance PV technologies and manufacture practical PV products in a competitive electricity market. Future R&D projects for PV could include improving the PV performance, enhancing the application of PV for residential and grid-connected operations by reducing the capital cost of PV, standardization of equipment and project approval permitting and interconnection procedures, and outreach for better educating the public, professionals, and policymakers about the potential benefits of PV.

Trends in PV Utilization

The annual rate of PV utilization grew worldwide from 20% in 1994 to 40% in 2000. Figure 2 shows that by the end of 2002, close to 1,330 MW of PV capacity was installed throughout the world (see www.iea-pvps.org). The majority of the 2002 growth was in Japan and Germany, which accounted for the 79% of PV capacity installed during that year. In terms of installed PV per capita, Japan continues to lead the way with 5 W per capita which is significantly above that of Germany (3.4 W). The PV capacity installed in 2002 in these countries is still a high proportion of the total size of the market representing Japan (29%), Germany (30%), and the U.S. (21%). In all cases, high rates of growth continue to be driven by government or utility supported programs that tend to concentrate on grid-connected PV in urban environments. By most estimates the off-grid market continues to grow at 15–20% per year while the grid-connected market is expanding at a healthy rate of 25–30% per year (see www.iea-pvps.org).

The PV industry in the United States is projected to provide up to 15% (about 3 GW) of the *new* U.S. electricity generating capacity by 2020. By then, the *cumulative* installed PV capacity of 15 GW in the U.S. and 70 GW worldwide is anticipated. A number of states with mandates

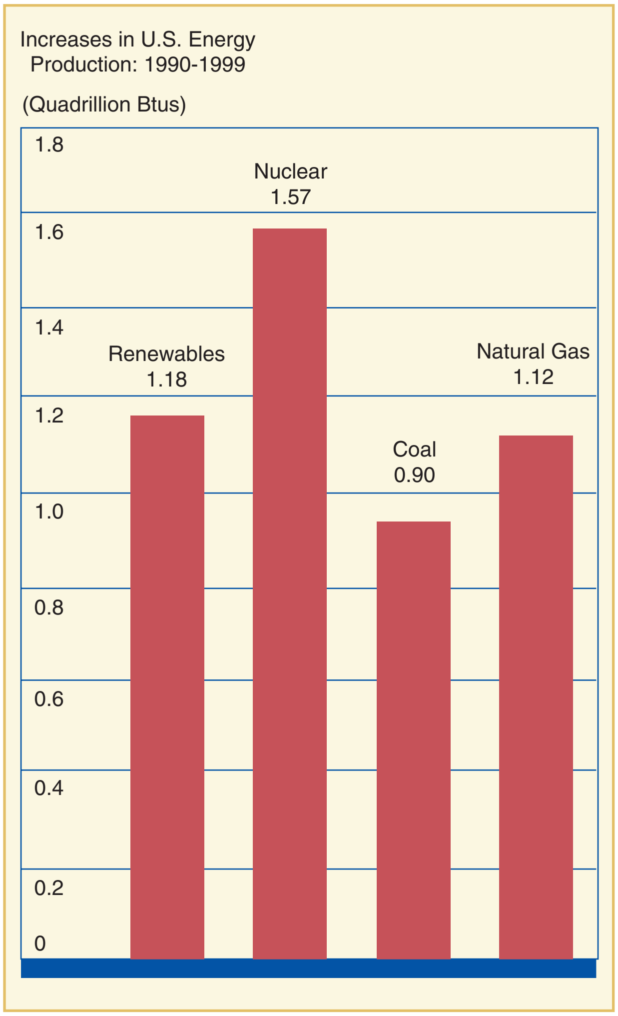

figure 1. Increase in U.S. energy production.

and renewable portfolio standards in place are projected to add significant amounts of renewable capacity including Massachusetts (1,112 MW), Texas (1,001 MW), Nevada (778 MW), California (623 MW), Minnesota (399 MW), New Jersey (340 MW), and New York (335 MW). Other States with smaller mandate requirements include Arizona, Hawaii, Iowa, Illinois, Montana, Oregon, West Virginia, and Wisconsin. Most of the new capacity is expected to be constructed in the near term (i.e., 60% by 2005) (see www.iea-pvps.org, www.eia.doe.gov).

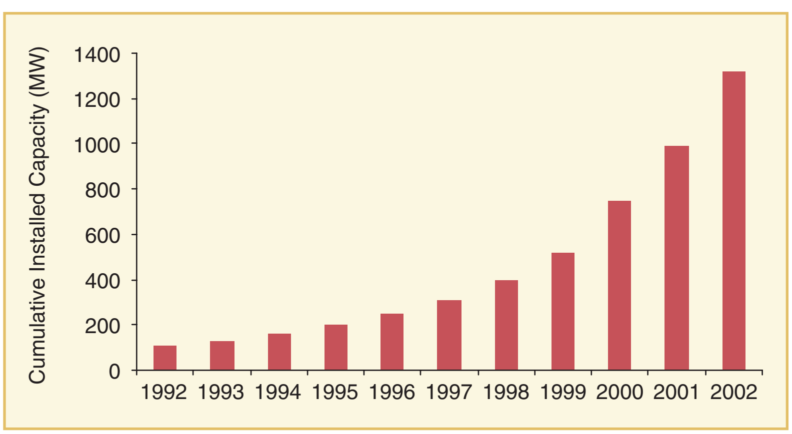

figure 2. Worldwide installed PV power.

How Is PV Generated?

PV science is the science of turning energy produced from the sun into electricity. Outside the atmosphere the intensity of solar radiation is about 1,300 W/m^2. When this energy is passed through the Earth's atmosphere, portions are scattered and absorbed by particles in the sky, like clouds or haze. Depending on the area, more than 90% of the solar radiation can reach the ground. In Las Vegas, solar values can reach 1,100 W/m^2. Figure 3 represents the world's solar energy map calculated at yearly averages (www.eia.doe.gov). The lighter colored areas have the highest energy potentials. At a closer look, Figure 4 shows the potential for the utilization of PV energy in the United States (see National Energy Policy in "For Further Reading").

It was Edmond Becquerel who discovered in 1839 the concept known as the PV effect. However, the first positive/negative (p/n) junction solar cell was not created until 1954 at Bell Labs. Figure 5 is a photo of the three inventors of the silicon solar cell—the first solar cell to convert enough photons for practical power. Gerald Pearson, Daryl Chapin, and Calvin Fuller (from left), the principal developers of the silicon solar cell, are shown measuring the electrical energy produced by several of their cells when exposed to light. A PV cell is a solid-state semiconductor device that converts light directly into electricity. A PV cell is usually made of silicon with traces of other elements and is the first cousin to transistors, LEDs, and other electronic devices.

Figure 6 depicts a simple representation of a PV cell (see www.bpsolar.com). A silicon atom has 14 electrons arranged in three different shells. The inner two shells have the maximum number of electrons so the inner rings are full. However, the outer shell has only four electrons, making it only half full. Since the outer shell is not full, the silicon atoms will share electrons with their neighbors to balance the structure. The jointing of these silicon atoms forms a crystalline structure. Since this type of structure is not conducive to conductivity, impurities such as phosphorous will be added. Phosphorous has five electrons in its outer shell, so phosphorous will bond with the silicon but one electron will not bond. In other words, it is loosely bonded with a proton in the nucleus of the phosphorous atom. When energy is added to this silicon, for example in heat or light form, it can cause a few electrons to break free of their bonds and leave the atoms. The electrons that are roaming are called free carriers, which carry an electrical current. This electron flow produces a current and the cell's electric field produces a voltage; in turn, power is produced.

Although all this sounds great, a PV cell absorbs only 15% to 25% of the sunlight's energy. A certain amount of energy is required to knock an electron free; for crystalline silicon it's about 1.1 eV. If a photon does not have enough energy, it just passes through the material, and if it has too much energy, the extra energy is lost. Other losses in a PV cell occur because of the silicon itself. Silicon is a semiconductor (which means it is not that good of a conductor), so its resistance is fairly high in causing losses. To minimize these losses the PV cell is covered by a metallic contact grid, which is a great conductor, so it shortens the distance the electrons have to travel through the silicon. However, this metallic grid could block some of photons (see www.bpsolar.com, www.oja-services.nl/iea-pvps/pv/home.htm).

Through the 1960s, research and development on PV continued largely for powering satellites and space probes. In 1968 industrial chemist Elliott Berman decided to build a solar cell cheap enough for terrestrial applications. He obtained financial backing for the project from Exxon in 1969. Berman and coworkers set their sights on the remote power market. The first big market for solar cells developed in the oil fields in the Gulf of Mexico where the offshore rigs required warning lights and horns but did not have their own power. PV proved cheaper to install and maintain than primary batteries, which is the other choice of electricity for these aids of navigation.

In the 1970s the first commercial PV products were introduced when the public demanded an alternative source of fuel to offset oil crises and the government support for such initiatives grew further. Between 1973 and 1980 the oil companies ranked as the largest users of PV, and most fledgling PV companies like Solar Power Corporation (Berman's firm) and Solar Technologies International (Bill Yerkes' company) had their sales people situated primarily in Houston. The success of PV for oil rigs and for pipeline corrosion protection in the mid to late 1970s no doubt played a major role in oil companies purchasing PV companies. The oil firms saw PV work for them and became convinced of the technology's potential (see Perlin in "For Further Reading").

Oil companies' enthusiasm for developing PV products has fluctuated over the years depending on the energy market and now appears to be on an upswing mode again. For example, BP Solar, which claims a global market share of 20% and annual revenues of more than $200 million, produced approximately 40 MW of PV in 2000 and has an extensive PV initiative for rural electrification in Southeast Asia and the heavily subsidized residential market in Japan.

The following types of PV are among those in commercial production or nearing commercialization:

- ✔ Monocrystalline cells, the direct descendants of Bell cells, are made of thin wafers sliced from large single crystals of silicon. These cells remain the most efficient PV available with system efficiencies averaging 12% in typical commercial products.
- ✔ Polycrystalline cells are composed of ribbons or wafers containing many silicon crystals fused together, which makes them less efficient but also less expensive to produce. Typical system efficiencies are approximately 10%. Because they are easier and more economical to manufacture, polycrystalline cells are used in many commercial applications for which space is not a critical constraint.
- ✔ Thin-film PV is a new technology that promises great cost reduction through automation. It is made by layering microscopically thin coatings of semiconductor material onto an underlying material such as plastic, metal, or glass. Although the current efficiency is about 5%, the efficiency of thin-film PV in the laboratory is approaching that of crystalline PV. Thin-film PV can be more easily incorporated into building components such as roof shingles, siding, and window glass so that a structure can be built from the ground up to generate its own power. Most industry experts expect this building-integrated market to grow enormously and prices to drop to about US$1.80 per watt in 2030.

figure 3. World's solar energy map.

Economic Argument for PV

The economic argument for the utilization of PV technology is straightforward: large upfront costs are offset over time by generating free electricity that would otherwise need to be generated by and purchased from a utility. Nevertheless, retail customers, distribution companies, and other interested parties have different expectations of distributed PV. A homeowner might install PV to improve power quality and reliability, gain energy independence, or help the environment. A distribution company might invest in PV to strengthen weak areas of the grid and defer expensive transmission and distribution (T&D) upgrades. Governments support PV to reduce greenhouse gas emissions and enhance energy diversity and security.

PV technologies are still costly and have high capital costs per kW of capacity, which renders them riskier than most conventional power plants. However, PV risks are partially offset by modularity, short construction times, and societal benefits such as pollution-free production. Entities that utilized PV were traditionally interested in protecting the environment. But a straightforward economic argument is made increasingly in support of PV when compared to the projected cost of grid power over a PV system's lifetime. Thanks to lower manufacturing costs and existing subsidies, payback for residential systems has dropped to about 15 years, which is still quite a bit longer than the five to ten years required for commercial or institutional systems.

In general, on-site PV systems that do not require T&D support are worth roughly US$100–$200 per kW per year more than central station systems. The difference between on-site PV and a central station system is high sensitivity to the characteristics of the T&D system, costs of extending distribution lines, and other line-specific factors. The capital cost of the total PV systems, which produce 100 W or more, is generally between US$5 and US$30 per watt. The average energy production for each watt of installed PV capacity is between 2 and 6 Wh/day, depending on the season and location. Very dark conditions (in Alaska) and very bright conditions (in Arizona) could produce energy outside this range. The life-cycle cost of PV energy could range from US$0.20 to US$1.00/kWh (see www.bpsolar.com, www.oja-services.nl/iea-pvps/pv/home.htm).

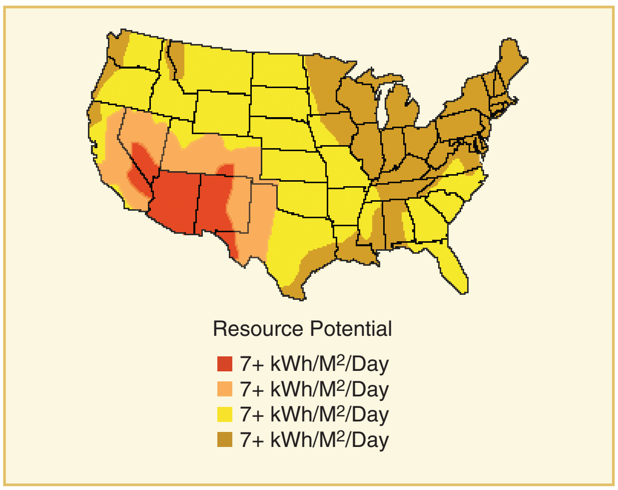

figure 4. U.S. solar insolation resources.

The cost of the PV modules is typically one-third to one-half of the total PV system cost. Also, dc to ac inverters that turn the dc electricity produced by a PV cell into ac electricity that would be used by most households could cost anywhere from 25 cents to US$1.50 per watt, which could significantly impact the total cost of building-integrated and rooftop PV systems.

However, the cost of utilizing PV might not be an entirely accurate reflection of the PV's added value because it is often not fitting to assign a monetary value to the benefits of PV. The most recognized added value of PV is its pollution-free feature in metropolitan areas. In addition, building-integrated PV applications can partially offset the cost of PV by enabling an already expensive component to help meet a building's electric load. PV in the form of shingles is used in place of traditional roofing materials in an almost indistinguishable fashion. PV is also deposited on window glasses, awnings, and skylights designed to pass varying amounts of light (see www.eere.energy.gov/pv, www.howstuffworks.com/solar-cell.htm).

Operation and Maintenance of PV

PV technologies could provide a more secure mode of operation for power systems during peak load hours when the systems are constrained and locational marginal prices are high. PV could further help the power industry achieve compliance with the Clean Air Act and other environmental regulations. PV cells are low-voltage dc devices that can be wired for higher voltages with no moving or wearing parts. The majority of PV cells make extensive use of silicon, which is nontoxic and the second most common element on the Earth's surface. Once installed, a PV array generally requires no maintenance other than an occasional cleaning. Many PV systems contain storage batteries that require some maintenance. The benefits of PV are listed as follows:

- ✔ clean energy source with a long life
- ✔ fixed cost of electricity (cents per kWh) for the life of PV
- ✔ pollution free and very quiet
- ✔ reliable with minimal maintenance
- ✔ competitive with other energy sources
- ✔ modular and expandable
- ✔ energy independent (requires no fuel) with no contribution to green house gases.

One criticism of early PV modules was that they consumed more energy during their production than they generated during their lifetime. With modern production methods and improved operational efficiencies, this criticism is no longer valid. The exact energy payback is dependent on the availability and the intensity of solar resource and on the degree to which the PV system is in operation.

At the same time, siting and climate can greatly affect both the lifespan and power rating of PV systems. Cycling PV systems through daily and seasonal temperature extremes could cause deterioration. In addition, the output of PV cells decreases with increased temperature. The open-circuit voltage of a PV module could drop by 0.2–0.5% for each degree of Celsius increase. PV usually works better in cooler weather and generates more power at lower temperatures. This is because, in temperate climates, PV generates less energy in the winter than in the summer, which is due to shorter days, lower sun angles, and greater cloud cover.

Lead-acid batteries, a key part of many PV systems, are very sensitive to temperature. Inverters could suffer from the same PV exposure to extreme cold, heat, or moisture, which could impact the inverter's durability. Many inverters are

PV technologies could provide a more secure mode of operation for power systems during peak load hours when the systems are constrained and locational marginal prices are high.

rated to operate at full load in ambient temperatures of 25 °C and must be derated at higher temperatures. While the lifespan of a PV module may span decades, inverters typically have life spans of 5 to 10 years. Simple measures, such as placing an inverter on the shady side of a structure sufficiently high to avoid back-splattered rain bouncing off the ground, can do much to improve performance and prevent premature failure. In addition, an inverter may be placed indoors where the dissipated heat while operating can be used for space heating.

Current Markets for PV

The value of PV in electricity markets depends on the amount and the value of energy that it offsets and the nontraditional benefits that it generates. These values differ widely from utility to utility and site to site, and even site to site within the same utility. The niche PV market that appears to have captured the public's imagination is rooftop PV. That is the flat-plate crystalline technology, the familiar blue-black panels that are typically mounted on the ground or on rooftops at an angle, facing the sun. Rooftop systems could reduce the load on distribution feeders and substations in essentially the same way as a centralized PV that provides T&D support. Rooftop PV systems also have no land cost for siting. However, the key attribute of rooftop PV systems that makes them a potentially significant niche market application is net offset retail electric rates rather than wholesale avoided costs. Retail electric rates are typically several times greater than avoided costs, which include costs related to T&D capital and operations, generating capacity, system overheads, etc.

The difference in cost creates considerable value for the residential customer at the expense of the utility. By valuing PV electricity at the retail offset (without a standby charge), the utility absorbs the costs above avoided cost. In a competitive market, absorption of these costs by utilities can only be substantiated by regulatory mandates. Nevertheless, PV technologies would require cost reductions or a combination of cost reductions, increase in subsidies, and an increase in natural gas prices to become cost competitive in most grid applications. On the other hand, niche applications, such as PV for T&D support at the end of a fully loaded distribution line, have value above that of a new generating plant. Such applications may permit the PV technology to establish itself and benefit from economies of scale.

An associated obstacle to valuing the market for PV is the way in which electric utilities conduct their resource planning. The avoided-cost methods to a great extent do not consider nonmarket benefits and the social benefits of PV energy. For instance, the environmental benefits of using the sun to produce electricity are not usually explicitly accounted for in resource planning. Because the environmental benefits of using cleaner technologies are dispersed and accrue to the general public, the decision-making utility has no direct incentive to take them into account. Therefore, even though PV technologies impose little or no pollution cost on society, that benefit is generally left out of the least-cost planning process.

figure 5. The three inventors of the silicon solar cell. (Property of AT&T archives. Reprinted with permission of AT&T.)

PV-Grid Interconnection

PV energy could play a greater role in meeting energy demands if it is integrated into existing grid systems. We distinguish here between two types of grid-connected PV systems. Small utility-interconnected PV systems can be used by private or public owners. Energy surplus will be fed into the grid, while at peak hours energy will be consumed from the grid. The other option is utility scale, central-station PV fields managed by the utilities in the same way as other electric power plants. The dc output of PV is converted to ac and then fed into the central utility grid after which it is distributed to customers. In a grid-connected PV, the grid acts like a battery with unlimited storage capacity. Therefore, the total efficiency of a grid-connected PV system will be better than the efficiency of a stand-alone system as there is virtually no limit to the storage capacity, and the generated electricity can always be stored.

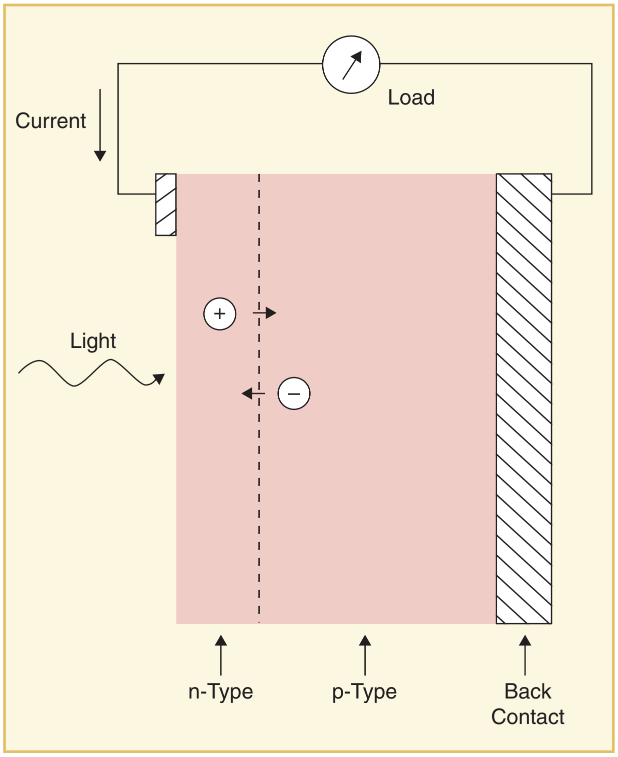

figure 6. Schematic of a PV cell.

The grid-connected PV system has many advantages. It is less expensive and more concentrated since the system could merely consist of photocells, dc to ac converters, and the interconnection equipment and controls. Also the grid-connected PV requires no storage system. The grid will supply the loads when it is dark or additional energy is required; this saves the cost of the battery storage system. In more sophisticated setups, both PV and battery could supply peak loads, and the utility could potentially benefit from the shaved peak demand, lower generation costs, and further investments in T&D and generating plants.

Integrating PV with the grid presents various challenges

figure 7. View of San Francisco's Moscone Convention Center 675-kW PV installation (photo by Mike Kim, SFPUC).

that energy companies, government, IEEE, and other stakeholders are planning to overcome. In general, utilities are concerned that on-site PV generation lessens their control of the distribution system and could result in unsafe conditions for line workers or the public, particularly when a circuit that is assumed to be de-energized is still being fed by a distributed generator. As the number of on-site PV generators on a particular circuit increases, the potential for power quality disturbances could grow. A key challenge for the industry is balancing the need of distribution companies to ensure system safety and reliability, on one hand, with the economic, environmental, and power quality interests of customers on the other.

An additional point to be discussed here when considering a breakthrough technology such as PV is a set of standards that need to be followed for its successful operation. There have been critical ongoing studies in terms of the formulation of standards through the IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems (IEEE Standard P1547). Some of the main goals of these studies are to provide manufacturers and end users with a well-defined set of operating and testing procedures to ensure safe operation. In addition, standards are devised to provide the necessary details for technical procedures. IEEE Standard P1547 facilitates the interconnection of one or more PV systems with the existing power system grid. It is of utmost importance that the policies depict uniformity in their usage. Otherwise, the impact could directly affect the market penetration of the related PV technology.

Recent technical standards developed by IEEE, Underwriters Laboratories (UL), and others will help define the capabilities, performance, and design requirements of PV. Issues such as surge protection, short-circuit protection, electrical isolation, communication, and control are being addressed in new interconnection policies that are fair to both distribution companies and distributed generation owners and operators. However, more studies are needed to evaluate how distributed generation and storage interacts with the electric distribution system, particularly as PV use expands. Avenues of research could include improved models and joint studies to assess possible impacts and suggest simple, inexpensive, and practical ways to minimize risks. One project now underway will assess the impacts of distributed PV on a mini grid. Supported by federal, state, and municipal sources, and by utilities and private sector entities, this testing will monitor the effects of different types of distributed generation at a test site in Northern California.

Since the advent of PV is taking place at a time when the electric power industry is undergoing a major restructuring phase, certain policies and regulations need to be followed by PV suppliers and manufacturers. Primarily, the aim of such policies is to create a competitive environment between a wide range of suppliers, thus giving the customer a larger number of options to choose from. One of the major marketing strategies involves incentives that commend PV suppliers for commercializing the technology aggressively in the market. The aim here is to initiate a healthy competition among PV suppliers. At the same time, it is of prime importance that the incentives not subsidize unused and overpriced PV equipment, or contribute overly to PV installers' bottom line. As is obvious, commercialization of a particular distributed generation technology, PV in this case, must comply with all aspects of electric power system restructuring policies.

Power industry restructuring in several states is opening electricity markets to new energy companies, including those dedicated to making and marketing green power. Regulatory efforts at state and federal levels, including new policies promulgated by DOE and FERC, aim to reduce or remove barriers to interconnecting distributed resources to the grid. Net metering programs in many states allow owners of distributed generation to feed excess electricity to the grid, in effect using it as a free and 100% efficient storage battery (in most cases the customer receives no direct payment from the host utility and the excess energy must be consumed within a month or year). This latter development is particularly important for distributed PV. In some cases, the ability to store energy on the grid for later use can eliminate the need for large and expensive energy storage systems such as batteries.

The tools that form the necessary interface between distributed energy systems and the grid need to be less expensive, faster, more reliable, more compact, and more accepted by utilities. Promising technologies exist that will improve the transmission, storage, and reliability of PV energy. An example of recent technological novelty is the high-temperature superconducting power transmission cables that the DOE is developing in partnership with industry. These cables will allow a 300% increase in capacity without the need for new transmission lines.

Snapshot of Worldwide PV Projects

(see www.oja-services.nl/iea-pvps/pv/home.htm)

Residential Projects

- ✔ Olympic Village, Sydney, Australia
- ✔ Mississauga House, Canada
- ✔ New Housing Area, Amersfoort, The Netherlands
- ✔ Lord House, Maine, USA
- ✔ Electric Sunflowers, USA
- ✔ Shea Homes, USA

Commercial and Institutional Buildings

- ✔ Energypark West, Satheins, Austria
- ✔ Center for Sustainable Living, Toronto, Canada
- ✔ Mont-Cenis Academy, Herne Sodingen, Germany
- ✔ Neubau Fraunhofer ISE, Freiburg, Germany
- ✔ Jubilee Campus, Nottingham University, United Kingdom
- ✔ Solar Office Doxford International, United Kingdom
- ✔ Children's Museum of Rome, Italy
- ✔ Tokyo Building of NTT Do Co Mo, Tokyo, Japan
- ✔ SBIC East Head Office Building, Japan
- ✔ Tsukuba Research Center, Japan
- ✔ Office Building and Research Laboratories, Petten, The Netherlands
- ✔ Universidad Verde, Jaén, Spain
- ✔ Göteborg Energi Facade, Sweden
- ✔ ABZ Marchwartstr, Zurich, Switzerland
- ✔ Wasgenring School House, Switzerland
- ✔ 4 Times Square, New York, USA
- ✔ State University of New York at Albany, USA
- ✔ Discovery Science Center Cube, California, USA
- ✔ Nature Conservancy's Conservation Learning Center, USA
- ✔ Moscone Convention Center, USA
- ✔ Santa Rita Jail, USA

PV Projects Underway in California

For examples of current PV projects one can look to California. The City of San Francisco has embarked upon an ambitious voter-backed program to support PV installations on municipal and private facilities, has aggressive plans to change the mix of electricity produced for use in the city, and believes PV has a strong role to play. With voter approval to issue over US$100M in revenue bonds to support renewable energy and efficiency, San Francisco has stepped to the forefront in the effort to build and sustain a strong market for PV in California. The first site in the city's program is a 675-kW system installed at San Francisco's Moscone Convention Center, which is shown in Figure 7. Subsequent requests for PV at municipal facilities are being issued, and the city also has plans to install 100 residential and commercial sites over the next few years. The Sacramento Municipal Utility District (SMUD) has been a leader in promoting and installing PV for over 10 years and is currently leading a nine-utility project to install PV systems at more than 200 residential, commercial, and industrial sites. Other California utilities in the project are Southern California Edison, the Northern California Power Agency, and the City of Anaheim. Another California project is a 5-MW central station PV power plant in Imperial County. The power will be sold to San Diego Gas & Electric. A fourth project of note in California is being managed by the California Construction Authority and is occurring at California fair grounds. A sampling of other projects worldwide can be found in the sidebar.

Conclusions

The development of the nation's energy sources will be influenced by energy demand, cost of energy development, conservation, and regulations that the government will put in place to meet energy needs while promoting the competition and protecting of the environment. In a competitive electricity environment, various states in the nation are pursuing the ability to further capture the energy of sunlight, the heat of the Earth, and the power of wind.

PV is a versatile power source and PV technologies have some unique attributes that drive their use in situations where most conventional energy technologies are not cost effective. PV modules have no moving parts to wear or break down and can be used for extended periods of time without much maintenance or intervention.

Despite some obstacles, PV energy technologies continue to enjoy success in certain market niches. PV prices and the delivered cost of PV energy have declined substantially in recent years. Major progress has been made in all areas of module performance, reliability, and cost. However, in most cases, PV systems are not commercially available for extensive grid-connected applications. As restructuring of power generating companies evolves and energy prices continue to decline, customer loyalty and retention will be playing an increasingly important role in utilities' decision making. With increased competition, a partial answer may be green pricing, in which consumers who choose to pay more for clean, renewable energy have the option to do so. In other cases, a partial answer may be portfolio standards whereby a retail utility is required to obtain part of its energy from renewable sources. Many jurisdictions, including California, are considering portfolio standards for the near future.

It is noted that public-private partnerships that combine the technical, economic, and regulatory expertise of many parties in ways that would not be financially feasible for the private sector alone are the key to PV technology development. To a certain degree, the government role in these partnerships reflects the notion of societal benefits such as reduced air emissions and reduced oil imports that cannot be properly valued by electric utilities and nonutility generators. In the long term, PV technologies must become more competitive in their own right either through lower costs or through explicit recognition of external costs of conventional energy supplies.

An interesting movement currently gaining momentum across the United States results from the understanding that the municipal level (in cities) is where a lot of the PV activity occurs, and events like the recently held "Solar Cities Summit" in San Francisco recognize and advance the role cities can have in the repositioning of solar power as mainstream energy and in supporting the development of markets for PV.

Acknowledgment

This work is supported in part by a grant from the Energy Storage Program at the U.S. Department of Energy (Dr. Imre Gyuk, program manager).

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