Solar Electric Technologies and Applications

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ABSTRACT

Solar electric power or photovoltaics (PV) utilize sunlight to produce electricity. PV cells are connected to create modules that, along with the balance of system, comprise a PV system. The electrical output of a PV system is determined by using design models, or measuring actual performance over a period of time. PV is a versatile, modular technology that can be adapted for almost any application, including residential and commercial applications, using a variety of business strategies. The costs of PV have decreased for large applications; however for smaller systems, the costs remain unstable. Cost is only one of the barriers to commercialization; others include interconnection, an uneducated market, and technology reliability issues. SEPA's Solar Power Solutions program has been designed to address these and other barriers.

INTRODUCTION

In 1992 the Solar Electric Power Association (SEPA) was formed to bridge the gap between energy service providers and the PV industry. During the 10 years of its existence, SEPA has developed unique knowledge of PV based on the Association's relationship with both the energy service and PV industries. The 6-year-long Technology Experience to Accelerate Markets in Utility Photovoltaics (TEAM-UP) program, and now, Solar Power Solutions (SPS) have provided an opportunity for SEPA to study a wide range of PV technologies and applications.

SOLAR ELECTRIC POWER OR PV BACKGROUND INFORMATION

Solar electric power or photovoltaic cells utilize solid-state technology to produce electric energy directly from the sun. Cells are wired together and laminated in a sealed package called a module, which can be mounted on a roof, packaged into roofing or other building products, or installed on the ground. The solar electric power is produced as direct current (DC) power. PV modules are usually measured in kW, and come with a nameplate rating in kW STC (standard test conditions). An alternating current (AC) power rating in kW PTC (PVUSA test conditions) gives a closer estimate to the actual system output.

Because utility grid systems operate on alternating current, or ac power, grid-connected applications of photovoltaic modules require an inverter to convert the DC output to AC power. These inverters also provide intelligence to disconnect the PV module from the grid when the grid is de-energized. Solar electric systems designed to operate independently when the grid is "down" require energy storage, typically in the form of a battery, similar to a car battery.

Solar electric power systems, therefore, can have different requirements, can utilize different types of solar modules and, indeed, can be mounted in a variety of building and on-ground environments. Further, they can provide different and varying benefits to the consumer or building owner and local utility or other energy service company, depending upon the characteristics of the installation and the local electric service. Thus is born an environment whereby the development of useful, profitable business models is of interest to those whose mission is making solar electric service a mainstream energy choice.[1]

AVAILABLE TECHNOLOGIES

There are a number of different technologies available, each varying in cost and efficiency. A few examples of the available technologies are listed in Table 1.

PV SYSTEM COMPONENTS

The PV modules are only one component of the entire system. The other components are the inverter, mounting system, and wiring, etc.

Table 1. Photovoltaic Technologies[2]

Single-crystal silicon with its high efficiency, is the technology of choice for telecommunications and other industrial applications, where "best performance" is a criterion.
Multi-crystalline or polycrystalline silicon is a prevalent technology for rooftop applications, where there are some space limitations - hence relevance of efficiency - but also price sensitivity. Similar technologies developed with new manufacturing processes include "ribbon" or "sheet" silicon.
Amorphous silicon (a-Si) is a thin film technology, and tends to have lower efficiency than crystalline silicone but also tends to have a lower cost per peak watt. It has been the technology of choice for small demand consumer products, such as watches and calculators, and for applications requiring performance under low-light conditions or partial shading.
Thin-film technologies such as cadmium telluride (CdTe), and copper indium diselenide (CIS) are valid for many of the same applications as amorphous silicon. Some environmental concerns exist about the materials used in their manufacture.
Concentrator PV may use a number of technologies; a small area of cells receives sunlight under high concentration. Concentrator PV is most effective where sunlight is intense, direct, and rarely interrupted, and so is well suited to geographic areas such as the Desert Southwest.
Multi-junction cells include emerging technologies such as gallium arsenide and gallium indium phosphide. These cells show high conversion efficiency either under concentration or normal sunlight, and are a promising technology for the future.
Dye-sensitized solar cells include a number of emerging technologies such as the TiO_2-based Gratzel cells and new developments such as self-assembling organic PV layers.

The inverter converts the direct current produced by the PV modules to alternating current to either power the home/building it is associated with or is directly fed into the utility grid. The inverter is generally acknowledged to be the weak point in the PV system, and is the most frequent cause for failures and malfunctions. The inverter industry has been making progress to correct that, and inverters are becoming increasingly more reliable.

Most PV systems are ground-mounted or roof-mounted, and both have advantages and disadvantages associated with them. Ground-mounted PV systems can take up considerable amounts of space, and there is a potential for vandalism or theft and the system can pose a safety hazard. Ground-mounted systems can be stationary, one axis tracking, or two axis tracking systems. Tracking systems have a greater power output, but generally have a higher initial cost and may require additional maintenance.

Roof-mounted systems take advantage of unused roof space; however, there is a risk of compromising the roof's integrity by installing PV systems that penetrate the roof. This may invalidate the roof's warranty and may cause leaking. Structure and foundation costs can be minimized with roof-mounted PV systems. The roofing structure's orientation, roof shape and shading may cause the PV system to perform below the expected rating.

PV SYSTEM RATINGS

In the final analysis, what customers most want to know is the level of energy production they can expect, which, in turn, depends not only on the system characteristics but also on the weather at the specific site, a variable that can be enormously inconsistent.

To determine actual AC ratings, the system output must be measured under real operating conditions (which vary with time). There are some design models that will also give accurate estimates of the system's output. That data is used to calculate a rating for each system. Data acquisition systems can be used to provide measured data points for AC output, plane of array irradience, ambient temperature, and wind speed. These data points can be used to estimate the rating, using a mathematical regression with the following equation[3]:

$$X = A^*Irr + B^*Irr^2 + C^*Irr^*T_{amb} + D^*\ Irr^*WS$$

where: X = system output power, kWac
Irr = irradiance, W/m^2
T_{amb} = ambient air temperature, degrees C
WS = wind speed, m/s

PV APPLICATIONS

One advantage PV has over many renewable energy technologies is its versatility; the systems are modular and can be adapted to almost any shape or size, and can be sited close or at the intended electrical load. There are several applications for PV, including residential, commercial, and utility scale. The various technologies can be used to develop the ideal PV system for a specific application. Each application has advantages and disadvantages, which will be discussed in the "Barriers to Solar Electric Power" section.

Residential PV systems are usually roof-mounted and less than 5 kW. These systems, because of their smaller size, generally have a higher cost/watt than larger systems because the balance of system (BOS) costs are somewhat independent of size. Reliability and maintenance are also challenges that face residential systems. The smaller inverters used for residential systems are often the most unreliable portion of the system, and without some form of monitoring, it is difficult to determine if their system is operating correctly.

Large commercial and utility-scale PV systems are usually more cost effective than residential systems. Systems over 70 kW have shown a decrease in costs since 1996[4]. Commercial systems and utility-scale systems tend to be larger than residential systems; however, their size varies considerably. Data acquisition systems are important for large systems because a loss of power equates to a loss of money, generally accounted for as savings on an electric bill.

Recently there has been a movement toward utilizing building integrated photovoltaics (BIPV). BIPV can be incorporated into the design of a new building or added on to an existing building. When a building is designed with the PV system in mind, PV system performance can be optimized.

PV MARKETS AND BUSINESS MODELS

Through working with its members and with the TEAM-UP and SPS programs, SEPA has identified a number of sustainable, replicable business models that can be used to move PV into mainstream energy markets. Table 2 identifies widely used business strategies identified by SEPA.

Table 2. Business Strategies

The Community-based Model involves a public-private partnership between community groups, local businesses, local utilities, local government, and others. Community involvement and support can help to resolve problems and address barriers to implementation by strengthening the local infrastructure.
Green Pricing programs create special energy products or mixes for which customers pay a premium on their electric bills to support "green" electricity. Green pricing can refer to wind, biomass, and other generation resources.
Schools and Public Buildings that utilize photovoltaics help to increase the visibility of solar and raise community awareness of solar. Schools and, to a lesser degree, public buildings with PV systems provide an excellent educational opportunity for students and the community to learn about energy, the environment, and related issues. In addition to the educational benefits, schools usually have flat roofs ideal for PV systems, and their peak demand coincides with the peak output of PV systems.
Dealership Networks consist of multiple strategic alliances with distributors who market and sell similar products. Distributors are local or national businesses that earn their revenues and profit from the product sales and the labor sold for installation and maintenance. This model is expanding to include home builders and developers who are partnering with the PV industry and energy service providers to build new homes with PV systems incorporated into the design.
Utility Partnerships use the strengths of the local utility to promote PV. Utilities can augment the technical knowledge of the venture by bringing additional resources and customer credibility. By pooling their resources, all partners benefit. Utilities are judged by some to be the key to taking PV into the mainstream with the lowest marketing and financing costs.

PV SYSTEM COSTS

From 1995 through 2000, SEPA collected detailed cost data on the 1100 systems installed as part of the TEAM-UP program. This data showed that large-scale systems (systems over 70 kW) had the lowest costs on a dollar per watt basis, and that costs for these systems decreased steadily over time. Costs for residential systems remained relatively stable.

Large Systems

Cost data were collected from 23 PV systems with a generating capacity of between 70 kW to over 400 kW. System costs ranged from a low of US$5.31/W to a high of US$11.82/W. Large PV systems differ in many ways, which posed some difficulty when comparing system costs. For example, single-axis tracking systems require tracker mechanisms and installation, while roof-mounted systems may require cranes and expensive roof modifications. The availability of state tax credits or incentives, site-specific installation and interconnection requirements, and varying labor costs may all have significant effects on total project cost.

As shown in Figure 1, system costs decreased from 1996 to 2000, with the exception of the year 1999. The increase in 1999 was most likely caused by an increased demand for PV systems. Several systems completed in 1998 and 2000 were installed by experienced project leaders, partially explaining the steep decline in costs in 1998 and 2000.

Several factors contributed to decreasing cost trends. Module costs declined by year, with the exception of 1999; project leaders learned to reduce costs as they gained experience; long-term contracts ensured stable prices; and installation experience led to system ratings at or near the expected level. However, module cost data indicates that they were the largest factor in the overall cost reductions from 1996 to 2000.

Residential Systems

Over 600 residential PV systems were installed as part of the TEAM-UP program from 1995 to 2000. The data collected from these systems shows that the installed cost of small PV systems continues to be unpredictable.

Early in the TEAM-UP program the residential systems installed

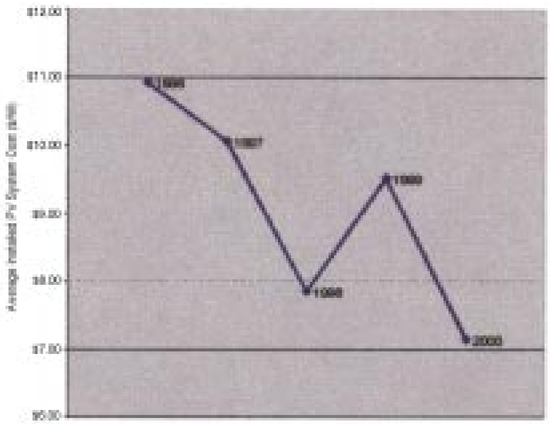

Figure 1. Average Installed Cost for Large-scale Systems vs. Installation Year

were large, customized systems. By the later years of the program (1999 and 2000), the majority of the systems installed were 1.5 kW or less, and many were standardized packages. Many of these later year systems were AC modules with ratings of 500 watts or less. As standardized systems are developed, costs will stabilize, and installation will become easier.

Figure 2 illustrates the cost per watt for residential systems when organized by size. As is expected, system costs are notably higher per kilowatt for systems less than 1.5 kilowatts (AC) in size. The total installed cost for systems larger than 1.5 kilowatts is relatively stable. Smaller systems must incorporate installation and overhead expenses, increasing the cost per watt. Also, many of the smaller systems are AC modules that have a relatively higher cost because it's a relatively new technology.[6]

BARRIERS

Despite the advances that the PV industry has made over the years, a number of barriers still exist. The primary obstacle to market penetration is the high initial cost of the systems. Currently there are various federal, state, and local programs available to help bring down the cost of solar. The key to market penetration is increased demand, which is needed to enable manufacturers to expand factories and implement new

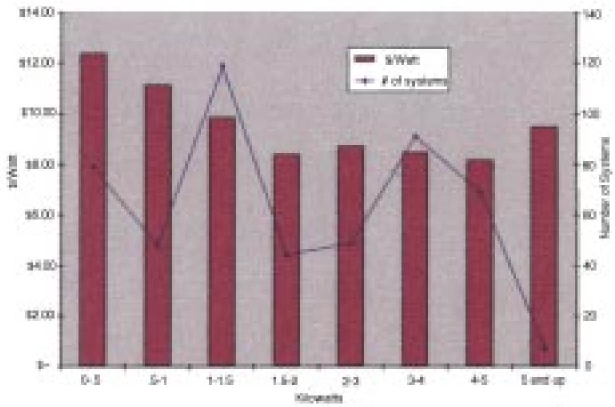

Figure 2. Residential System Costs and Number of Installations by kW

manufacturing processes. This will lead to economies of production, and reduced costs.

The technology has made significant improvements in efficiency and reliability; however, these issues remain an obstacle for the industry. As some manufacturers move to standardized systems, many of the problems are being resolved. However, inverters remain the weak element of the system, and the systems still require frequent maintenance. One problem that consumers encounter is that it is difficult for the average person to determine if their PV system is operating properly. This results in a loss of potential electricity generation. The alternative to this is to install a monitoring system; however, for small PV systems, this can be very expensive.

When compared with traditional electricity production, solar is prohibitively expensive. However, the true value of solar is difficult to define, and is dependent on perspective. Many consumers lack basic knowledge about solar and even if they have that information, they may not know where or how to procure a solar electric system. Educating the consumer on both the values and the industry is critical to market penetration.

Many areas are developing a strong local infrastructure to support the needs of the PV industry. This development is critical to providing installation and maintenance support to large- and small-scale consumers. There has been significant progress strengthening the local infrastructure in some areas, but the majority of the US lacks the local support for the PV industry that is necessary to advance commercialization.

Energy service providers (ESPs) can be both the key and a barrier to the advancement of solar technology. While ESPs often have available capital to finance large projects, they may lack basic PV technology knowledge. The interconnection of solar to the electricity grid is often technically and financially difficult. ESPs are in a position to make interconnection very easy, or prohibitively difficult and expensive. Several ESPs have mechanisms in place for easy interconnection; however, the majority do not. Net metering compensates the owner of a PV system for the excess electricity that the system produces and feeds back into the utility grid. This is another issue that faces the PV industry and directly involves ESPs. A number of states and ESPs have developed net-metering policies, but these are not uniform.[7]

SOLAR POWER SOLUTIONS

The Solar Electric Power Association, with funding from the U.S. Department of Energy, has developed Solar Power Solution (SPS), a program designed to address the barriers to commercialization and market penetration. SPS has two components, a report entitled *Solar Power Solutions: A Business Case for Capturing Total Value*, and funding awards for two "showcase projects." The report, available on SEPA's website *www.SolarElectricPower.org*, analyzes the past, present, and future of the solar industry; identifies the barriers to commercialization; and offers recommendations on how to overcome those barriers. The showcase projects were selected because their programs are innovative examples of ways to accelerate the solar market. More information on SPS and the showcase projects is also available on SEPA's website.

CONCLUSIONS

Photovoltaic technologies are advancing, and fill a unique niche in the energy market. Because PV can be adapted for any need or size, whether residential or commercial, it has an important advantage over other renewable technologies. Through TEAM-UP and SPS, several market strategies have been identified that have led to successful business ventures. Costs have been stabilizing, and for some applications costs are decreasing. ESPs and the PV industry have progressed toward making PV a more mainstream technology. ESPs are working with a variety of stakeholders to develop interconnection and net metering policies, and the PV industry has made improvements in efficiency and reliability. While there are still a number of barriers to commercialization, PV is rapidly advancing toward that goal.

References

1. TEAM-UP, Business Models Report, SEPA 2001, pg. vi
2. Solar Power Solutions: A Business Case for Capturing Total Value, SEPA 2002, pg. 9
3. TEAM-UP, Performance Data Report, SEPA 2001.
4. TEAM-UP, Large Scale Cost Report, SEPA 2001.
5. TEAM-UP, Business Models Report, SEPA 2001.
6. TEAM-UP, Residential Cost Report, SEPA 2001.
7. Solar Power Solutions: A Business Case for Capturing Total Value, SEPA 2002.