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COMMERCIALIZING PHOTOVOLTAICS: THE IMPORTANCE OF CAPTURING DISTRIBUTED BENEFITS

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ABSTRACT

The results of an empirical, case-study analysis demonstrate that PV will become cost-effective as a distributed resource long before it becomes a cost-effective, central station, energy supply option. This conclusion is based on the assumption that the non-traditional benefits that distributed PV systems offer to the electrical system and to utility customers, including transmission and distribution equipment deferrals and peak-shaving, are incorporated into cost-effectiveness analyses. The paper concludes that it is critical to capture the non-traditional or "distributed" benefits associated with investments in dispersed PV systems in order to commercialize the technology in grid-connected applications.

1. BACKGROUND

1.1 The Distributed Utility Concept

In the early 1990s, the distributed utility (DU) concept was developed to describe a future electric utility structure that could emerge from technology, customer, and public policy changes. The DU concept describes a utility structure in which small scale generation, storage, and targeted energy efficiency programs are used to cost-effectively augment the existing centralized energy production and delivery system (1). Several utilities set out to describe and quantify the benefits to the utility system from targeted energy efficiency programs and strategically sited, distributed storage and generation technologies. Several studies concluded that distributed generation technologies, like photovoltaics (PV), can offer additional benefits to electric utility companies and their customers beyond energy and capacity (2). Specifically, strategically sited PV systems can allow an electric utility company to defer investments in upgrading transmission and distribution facilities, among other non-traditional benefits. Through capturing these benefits PV was nearing cost-effectiveness in certain niche, grid-connected applications (3).

1.2 Electric Utility Deregulation

Shortly after the DU concept was first introduced, several states in the U.S. began to investigate restructuring the electric utility industry to allow retail customer choice. The drive to deregulate the electric utility industry is largely motivated by the large divergence between average (embedded) cost of electricity and the marginal cost of new capacity. Many analysts believe that a competitive generation market could save electric utility customers billions of dollars each year through lower rates (4). In short, attention was diverted from the DU concept due, in part, to the fact that it would be difficult to achieve the coordination and integrated planning associated with the DU concept under a restructured electric utility industry. Several states have begun to introduce retail competition into the electric utility sector beginning in 1998, including California, New Hampshire, Pennsylvania, Rhode Island, and Montana. Most other states plan, or are planning, to move toward retail competition within the next three to five years. Acknowledging that the social objectives that were once obtained under rate-of-return regulation will be lost in a deregulated environment, many states are including provisions in their restructuring plans to acquire these “stranded” benefits. In general, system benefits charges and renewable energy portfolio standards are being considered to assure continued investments in energy efficiency and “green” energy resources. While these measures are important and beneficial, few states have seriously considered how to treat the distributed benefits associated with targeted energy efficiency programs and distributed storage and generation.

2. ANALYSIS

The break-even price for PV in centralized energy supply and distributed peak-shaving applications were calculated for a case-study utility located in the mid-Atlantic region. These values were then compared to the projected future price of PV technology to determine when we would begin to see PV penetrate the mid-Atlantic, electric utility market in grid-connected applications. This section describes this analysis.

2.1 PV as a Central Station Supply Option

In general, electric utility companies’ experience with central station PV power plants is limited. However, several large-scale PV demonstration projects have been constructed. In the mid-1980s, the Sacramento Municipal Utility District, with financial support from the US Department of Energy (DOE), installed two 1 MW PV power plants. The largest PV power plant, rated at 6.5 MWp, was constructed in 1984 at Carissa Plains, California. This PV power plant has been operating by computer with no on-site staff and has been providing reliable electricity ever since it was first put into operation (5). A joint government-industry research and development program for PV was formed in 1986 called PV for Utility Scale Applications (PVUSA). PVUSA operates a test site in Davis, California in which PV technologies are tested, along with balance of system components, to gain experience with various technologies.

The break-even price of PV as a centralized, supply-side technology was estimated for the PV technology most likely to offer significant cost reductions in the near future, thin-film amorphous silicon. As a centralized energy supply option, a large-scale PV system is deployed at central location. The break-even price refers to the PV module price that allows PV to successfully compete with conventional fossil fuel electric generation options. In other words, at the break-even module price, PV-generated electricity costs the same as electricity produced using conventional fossil fuel supply options. The U.S. Department of Energy’s Energy Information Administration (EIA) produces an annual report that includes estimates of the cost of producing electricity from various fuel sources. According to the EIA, the cost of producing electricity using coal or natural gas will be approximately 5¢/kWh ($1995) over the next ten to fifteen years (6). The actual cost of producing electricity could be higher or lower than this; however, for purposes of this analysis we use the EIA’s estimate.

The break-even cost of PV as a central station supply-side option can be calculated using the EIA’s estimates of the cost of producing electricity. The break-even cost for thin-film amorphous silicon PV modules equals the price at which PV-generated electricity equals the EIA’s estimate of the future cost of producing electricity from fossil fuel alternatives. It is assumed that PV will be introduced as a centralized supply option in the mid-Atlantic region when a PV power plant can produce electricity at or below the EIA’s projected price of producing electricity using coal or natural gas. Equation 1 (7) was used to solve for the PV module cost with the levelized cost of PV set at the EIA’s 5¢/kWh.

EQUATION 1: LEVELIZED COST OF PV-GENERATED POWER

Levelized Cost of PV [¢/kWh] = ((Module Costs [$/m2] + BOS Costs [$/m2]) * (Fixed Charge Rate * 1+ Indirect Cost Factor)) / ((Annual Solar Energy [kWh/m2/year]) * (System Efficiency) * (Sunlight-to-Electricity Conversion Efficiency) * (Inverter Efficiency)) + O&M

TABLE 1: KEY ASSUMPTIONS

Variable Name	Assumed Values
Area-Related BOS Costs ($/m^2)	$50/m^2
Power-related BOS Costs ($/kWp)	$150/kWp
Indirect Cost (% of Total Capital Costs)	25%
Fixed-Charge Rate	12%
O &M Expenses	0.154¢/kWh
System Efficiency	85%
Inverter Efficiency	95%
Annual Solar Radiation (kWh/m^2/year)	1,679 kWh/m^2/year

Using the assumptions presented in Table 1, and assuming the sunlight-to-electricity conversion efficiency predicted for the year 2010 of 14% (8), the break-even cost of thin-film amorphous silicon PV modules was calculated. To achieve electricity costs of 5¢/kWh in the mid-Atlantic region amorphous silicon PV modules must cost $20/kWp. This value is extremely sensitive to the solar resource level and the electric utility company's fix-charge rate. The break-even price of PV modules would be much higher in Arizona which has a greater solar resource than the mid-Atlantic region.

2.2 PV as a Distributed Peak-Shaving Resource

There are two distinctly different grid-connected applications for PV technologies. PV can be deployed as a central-station supply option, which was analyzed above, or PV can be deployed as a distributed peak-shaving technology. As a distributed peak-shaving technology, small PV systems are strategically sited within a utility's service territory to achieve a variety of technical and economic objectives.

The economic value of these systems depends on who owns the system and how the system is operated (9). For example, a commercial building owner derives value, in the form of bill savings, from the PV system by using it to shave the building's peak demand and reduce the amount of energy purchased from their local utility company. From the electric utility company's perspective, distributed peak-shaving PV systems offer capacity, energy, and distributed benefits. As a result, the value of distributed peak-shaving PV systems will be different depending on which party makes the investment. To capture the different ownership/operation possibilities, two different scenarios are investigated. The first scenario investigates the technical and economic performance of distributed peak-shaving PV from a large commercial building operator's perspective. The second scenario involves an analysis of a distributed peak-shaving system owned and operated by a mid-Atlantic utility.

The break-even cost of PV is calculated based on an analysis of the technology in a dispatchable peak-shaving role (10). The break-even cost of PV for a dispatchable peak-shaving system refers to the price of PV modules at which the life cycle benefits equal the life cycle costs. Currently, the US Department of Energy is funding the development of a commercially viable dispatchable peak-shaving PV system through their PV:BONUS program. The system being developed consists of a 10 kWp fixed tilt array with 46 kWh of storage. It is assumed that the case study system utilizes thin-film amorphous silicon solar cells. Analysts predict that this technology is likely to experience the most dramatic price reductions over the next few years as new continuous manufacturing techniques are adopted. Table 2 provides the key cost and technical assumptions for the dispatchable peak-shaving PV system analyzed.

TABLE 2: SYSTEM COST AND TECHNICAL ASSUMPTIONS

Variable	Assumed Value
Installed Battery Cost	$200/kWh
System Book Life	25 years
Battery Replacement Cost (every 7 years)	$150/kWh
Annual Maintenance Cost	$500
O&M Escalation Rate	2.9%
Equipment Depreciation Period	5 years
Inflation Rate	2.9%
Evaluation Period	25 years

A spreadsheet model, called PV Planner©, was used to estimate the break-even cost of PV modules for the dispatchable configuration described above. PV Planner© can easily and quickly assess the technical and economic performance of grid-connected PV applications, including dispatchable peak-shaving PV applications. The model was developed at the University of Delaware's Center for Energy and Environmental Policy under a National Renewable Energy Laboratory contract (11). The model was used to estimate break-even PV module costs from both customer- and utility-owner perspectives in the mid-Atlantic region for dispatchable, peak-shaving PV systems.

Distributed peak-shaving PV systems can provide both traditional bulk system benefits and non-traditional (distributed) benefits to utilities. PV technology is particularly well suited for peak-shaving due to the fact that it provides maximum power output during the periods that most utilities tend to experience peak-demand. Furthermore, PV is a modular technology that can be easily sited in both rural and urban areas in small increments as needed to satisfy a variety of technical and economic objectives.

In addition to the traditional energy and capacity benefits, the transmission and distribution (T&D) deferral benefit of dispatchable peak-shaving PV system was estimated using QuickScreen© (developed for the U.S. Department of Energy by the Pacific Energy Group) (12). The T&D deferral values estimated using QuickScreen were used in PV Planner© to complete the analysis.

It was assumed that the dispatchable peak-shaving PV system would be strategically sited in an area in the mid-Atlantic region in an effort to defer a T&D upgrade that is scheduled for the year 2001. Through conversations with a T&D planner for Delmarva Power, a utility with 2,800 MW of generating capacity serving customers in a three-state area of the mid-Atlantic region, it was determined that photovoltaics could be used to defer a $2,377,000 investment to upgrade a 7 1/2 mile transmission line that is tied into a feeder that serves a mid-Atlantic coastal city. The current transmission line's 96 MVA capacity is planned to be upgraded to 137 MVA in the year 2001. An analysis of the correlation between the cumulative solar resource and the load on the transmission line indicated that dispatchable peak-shaving PV could be used to effectively reduce the peak capacity requirements of the transmission line. Figure 1 clearly illustrates that the transmission line experiences peak demand during the mid-day hours in the summer. QuickScreen© utilized a regional load growth forecast and key financial parameters to estimated a value of $867/kW-year for deferring a $2,377,00 T&D upgrade investment using distributed PV technology. This value can be thought of as the avoided T&D cost which is considered a benefit in the analysis. The T&D benefits were combined with the capacity and energy benefits to estimate a break-even price for PV modules of $1,800/kWp from a utility-owner perspective when the technology is deployed as a dispatchable peak-shaving technology. Table 3 provides the key utility financial assumptions used in PV Planner©.

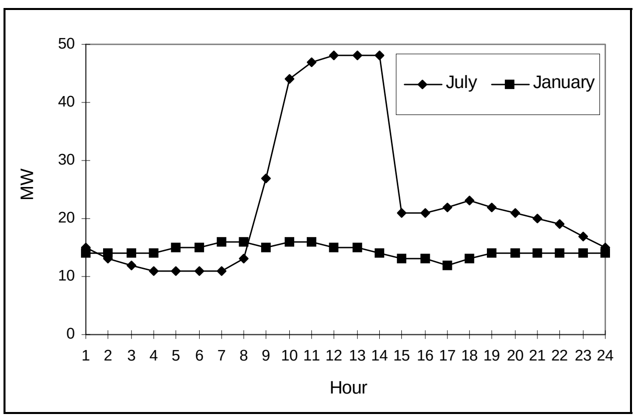

Fig. 1: Summer and Winter Feeder Load Profiles

Dispatchable peak-shaving PV systems can offer energy savings and peak demand reductions for commercial building owners, effectively reducing their electric bill paid to the local utility company. The break-even price equals the PV array price at which the present value benefits, in the form of bill savings and tax benefits, equal the present value capital and O&M costs. The bill savings were estimated based on the retail electricity rates for Delmarva Power. In addition, it was assumed that the utility would offer a financial incentive to customers investing in dispatchable PV systems in areas with T&D constraints. The assumed incentive equals 50% of the T&D deferral value estimated above to the utility from dispatchable peak-shaving PV.

TABLE 3: KEY UTILITY-PERSPECTIVE ASSUMPTIONS

Variable	Assumed Value
Utility Average Income Tax Rate	38.5%
Utility Debt-Equity Ratio	54%
Pre-Tax Return on Equity	10.23%
Interest on Debt	9.25%
Inflation Rate	2.9%
Evaluation Period	25 years

PV Planner© was used to solve for the break-even cost of PV as a distributed peak-shaving option for commercial building operators located in the mid-Atlantic region. The load profile for a typical large office building located in the mid-Atlantic region was used for the analysis. Figure 2 illustrates the building's load profile for a typical summer day. Table 4 provides the key financial assumptions utilized in the analysis. Based on the results, the break-even price for dispatchable PV from a building owner's perspective is $1,900/kWp. With PV module prices at this level, the lifecycle costs to the building operator equal the lifecycle benefits.

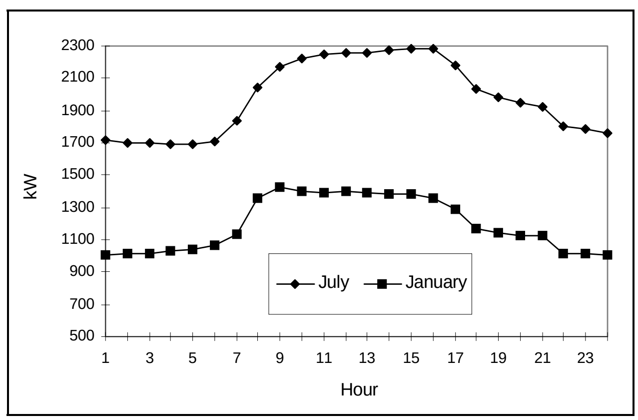

Fig. 2: Summer and Winter Load Profiles for Large Commercial Building

TABLE 4: KEY CUSTOMER-PERSPECTIVE ASSUMPTIONS

Variable	Assumed Value
Customer Average Income Tax Rate	39%
Customer Debt-Equity Ratio	100%
Customer Discount Rate	12%
Loan Rate	12%
Peak Demand Charge	$13.25/kW
Peak Energy Charge	$0.04/kWh

3. MARKET PENETRATION ANALYSIS

In this section, the break-even price of thin-film amorphous silicon PV in centralized energy supply and distributed peak-shaving applications is compared to projected future prices. Based on this comparison, the point in time when PV begins to penetrate the mid-Atlantic region's electrical system as a grid-connected technology is estimated.

Analysts predict that the price of PV modules will significantly decline over the next five to ten years. In particular, new continuous manufacturing techniques will likely yield significant price reductions for thin-film amorphous silicon PV modules. One analyst predicts that thin-film amorphous silicon PV modules will decline in cost from $3,000/kWp in 1995 to $2,000/kWp in 2000 and $1,500/kWp in the year 2010 (13). Although no one knows with certainty what actual PV modules prices will be in the year 2010, many analysts are optimistic that significant price reductions will occur, opening new markets for PV technologies. This optimism is based, in part, on the significant price reductions that have occurred over the past decade and recent technological advances in both the performance and manufacturing of PV technologies.

To determine when PV technologies will begin to penetrate the mid-Atlantic region's electrical system, the break-even prices of PV in central station supply and distributed peak-shaving applications are compared to the projected, future price of thin-film amorphous silicon PV modules. Figure 1 illustrates this comparison graphically. Each of the four curves presented in Figure 3 are in constant 1995 dollars for comparison purposes. One curve depicts the PV module price forecast for thin-film amorphous silicon PV technology. Two of the three straight lines represent the break-even price of PV as a distributed peak-shaving (PS) technology for electric utility companies and building operators respectively. The third straight line is almost on the y axis; this line depicts the break-even price of PV as a centralized energy supply option. The point at which the break-even price lines intersect the projected PV module price curve indicates when PV becomes a cost-effective resource in the mid-Atlantic region.

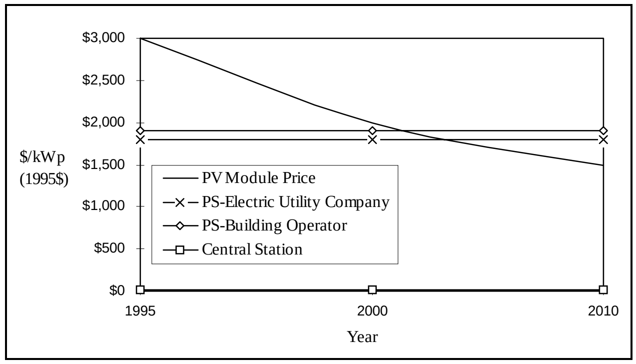

Fig. 3: Break-Even Price vs. PV Module Price Forecast

Figure 3 clearly illustrates that PV will become cost-effective as a distributed peak-shaving technology long before it becomes cost-effective as a centralized energy supply option in the mid-Atlantic region. Based on this market penetration analysis, thin-film amorphous silicon PV modules in distributed peak-shaving applications will become a cost-effective option for building operators and electric utility companies around the year 2003. In contrast, PV as a central station supply option will not be cost-effective in the foreseeable future. The early market penetration of PV as a distributed peak-shaving option will not be realized unless policies are initiated to bring about changes that encourage the adoption of cost-effective distributed resources. The current framework utilized by the electric utility sector does not consider the full range of benefits of distributed resources, such as local T&D upgrade deferrals. As competition emerges a, and utilities functionally unbundle their generation, transmission, and distribution services, it is less likely that they will consider the distributed benefits in making investment decisions.

This conclusion is consistent with a recent study conducted by the US Department of Energy's Energy Information Administration (EIA). The EIA uses the Electric Market Module (EMM), which is part of the National Energy Modeling System, to forecast which electric generation technologies will be used to meet new capacity requirements and replace retiring capacity. EMM is designed to model least-cost dispatch and capacity development overtime based on a central station approach to meeting the nation's electrical demand. The levelized costs of producing electricity from alternative technologies, including renewables, are compared to determine which technologies will be deployed to meet new capacity requirements.

The EMM analysis disaggregates the US electricity system into regions using the North American Reliability Council designation. According to the EIA's forecast, PV will not contribute to meeting capacity requirements in the mid-Atlantic region through the year 2015 (14). The EIA's analysis is consistent with the results of the analysis presented here, which demonstrate that the break-even cost of PV as a central station supply option supply options is well below the projected cost of PV modules through the year 2010.

4. CONCLUSIONS

Efforts to commercialize PV technology should focus on developing mechanisms to assure that the non-traditional benefits of distributed generation are captured in the cost-effectiveness analyses. It is unlikely that future efforts to internalize the external costs of fossil fuel generated electricity or customer willingness to pay would be sufficient to cover the premium associated with producing electricity from a central station PV power plant (15).

Mechanisms need to be developed to assure that cost-effective distributed resources are developed wherever and whenever they are appropriate. Renewable portfolio standards and system benefit charges are excellent policy tools to promote renewable energy. However, PV may likely not be used to satisfy these requirements unless provisions are included that ensure the value of distributed renewable resources are recognized. For example, in Vermont Docket No. 5854 *Vermont Department of Public Service Statewide Energy Efficiency Plan* describes a process under a deregulated market that assures that "Distribution utilities should attempt to defer or avoid as many such investments [T&D facilities upgrades] as economic and feasible with energy efficiency (16)." Similar language could be developed to assure investments in cost-effective dispersed PV installations.

A competitive wholesale market for electricity will put additional pressure to develop resources that offer the lowest cost of energy, a market in which PV will be unable to compete for at least two decades. The retail market, where distributed resources play a major role, must also recognize the value of distributed resources. Here the competition is not with the wholesale cost of energy but with the customer's cost of energy. This includes both the wholesale energy cost and the T&D costs. In this market there are additional mechanisms to enhance the penetration of PV. These include customer rebates, net metering, inclusion of PV in energy efficient mortgages and the removal of onerous interconnection requirements. These measures would assure investments in cost effective PV installations with earlier and greater penetration.

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