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COMMERCIAL BUILDING INTEGRATED PHOTOVOLTAICS: MARKET AND POLICY IMPLICATIONS

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BACKGROUND

As module prices have continued to decline (Maycock, 1995), interest in the technical and economic feasibility of using dispatchable photovoltaic (DPV) systems in peak-shaving applications on commercial buildings has grown. Currently, the United States Department of Energy is supporting the development of an integrated DPV peak shaving (DPV-PS) system for the commercial buildings sector through the PV:BONUS Program. Modest amounts of battery storage are used in conjunction with a PV array to achieve firm peak-shaving for commercial building operators. The development of this system involves the collaborative effort of the following organizations: Delmarva Power and Light Company (Delmarva); Center for Energy and Environmental Policy (CEEP); Applied Energy Group (AEG); AC Battery; Solarex; and Ascension Technology.

The technical feasibility of DPV-PS systems has been established through several demonstration projects. A DPV-PS system has been operating for over four years on Delmarva's Northern Division General Office located in Newark, Delaware. In addition, four DPV-PS systems have been installed at the following locations: a retail store in Green Bay, WI; the State Office Building in Wilmington, DE; Delmarva's Conowingo District Office in Northeast MD; and a manufacturing facility in Aberdeen, NC.

Close monitoring of the operation of these systems is providing data to further refine current system design and control strategies. In addition, detailed studies have been conducted at CEEP to assess the market potential of DPV-PS systems. Recent efforts have also included an investigation of emergency power as an added value to DPV-PS systems installed on specific building types.

This paper reports on the latest results in support of a U.S. Department of Energy PV-BONUS initiative to develop a commercially viable, modular, grid-connected DPV-PS system which also provides emergency power service for the commercial buildings sector.

In this study, we:

a) Assess the market for dual-function PV systems designed to serve peak-shaving and emergency power needs of the commercial buildings sector; and
b) Use the market assessment results to investigate policy options for promoting the adoption of dual-function PV systems in the commercial buildings sector.

CONCEPTS AND METHODOLOGY

PV systems can generate both energy value (the system's ability to save energy) and capacity value (in the form of coincident peak demand reduction) for commercial building owners. Generally, the economic viability of such systems depends on the solar resource, existing policy incentives, the conversion efficiencies of the components of the system, utility prices and customer demand characteristics.

A spreadsheet model that uses these variables to evaluate the economics of building applications of PV has been developed at CEEP to allow market assessment of PV systems. Called *PV Planner*, this model was developed with the support of the National Renewable Energy Laboratory (CEEP, 1996). The model is capable of simulating the performance of a PV system operating either as a dispatchable (i.e. with battery storage) or non-dispatchable (without battery storage) unit. Benefits and costs of both types of systems are based on accepted financial accounting procedures employed by commercial firms in the USA. Overall economic performance in each simulated case is expressed in terms of benefit-cost ratios and payback periods.

There are important differences in the way in which the demand reduction value of dispatchable and non-dispatchable systems are estimated in the model.

A non-dispatchable PV system would achieve demand reductions based on the output of the system at the time that the utility or building is experiencing peak demand. Equation 1 summarizes how the demand reduction value of such a system is estimated.

$$kW_r = kW^* - kW_{pv}^* \qquad (1)$$

where

kW_r = demand reduction of PV system
kW^* = utility/building peak demand
kW_{pv} = PV output at time of utility/building peak

A limitation of non-dispatchable systems is that the capacity value offered by the system in any given year is uncertain. Secondly, the time during which peak demand is experienced may not coincide with maximum solar insolation.

Dispatchable systems, on the other hand, may be deployed for peak-shaving purposes as and when needed, and can deliver a capacity value at least equal to the battery storage value of the system. Such systems can also be credited with the same peak reduction value given to a non-dispatchable system, based on array output at time of peak.

Previous analyses of dispatchable and non-dispatchable PV applications have established the higher economic value of the former (see Byrne et al, 1996 and 1995). For this reason, the paper focuses on the economic viability of dispatchable photovoltaic (DPV) systems in peak-shaving applications. Equation 2 (Byrne, et al, 1996) estimates the capacity or, equivalently, demand reduction value of a DPV-PS system.

$$kW_r = kW^* - (kW_{pv}^* + kW_{bat}) \qquad (2)$$

where,

kW_r = demand reduction of DPV-PS system
kW^* = building peak demand
kW_{pv} = PV output at time of building peak demand
kW_{bat} = battery bank output (net of round trip losses) at time of building peak demand

The kW_{bat} term represents the battery bank's output at the time the utility or building is experiencing its peak demand and is a function of the size of the battery bank and the number of dispatch hours.

In addition to the peak-shaving value of DPV-PS, this paper also reports on an analysis of emergency power (EP) as an added value of such systems (Byrne et al 1997a). The economic benefit of adding the EP function to a DPV-PS system is expressed as the *avoided cost* associated with the purchase and operation of conventional EP systems. Two forms of emergency power are considered - emergency lighting (EL) and uninterruptible power supply (UPS). The following assumptions are made:

a) For a DPV-PS configured to provide emergency lighting, the avoided cost is the cost of storage that would otherwise be required for the conventional EL function.
b) When UPS is provided, the avoided cost includes two components: (a) storage costs of conventional UPS systems; and (b) conversion losses due to the design of conventional on-line UPS systems;
c) The battery storage requirement for a specific EP function is sized at a given fraction (b_f) of the storage component (BAT[kW]);
d) Energy withdrawal is at 85% depth of discharge of the DPV-PS system battery bank; and
e) Running time (R_t) of the emergency power function is a standard 1.5 hours for EL and 0.25 hours for UPS.

Based on these assumptions, the total amount of storage capacity of a DPV-PS system that is assigned for emergency power purposes, was estimated by means of equation 3:

$$B_a = [b_f(BAT[kW]) * (0.85)/R_t] \qquad (3)$$

The total value added (V_{el}), to the DPV-PS system configured to provide an emergency lighting service is estimated by multiplying B_a by the lifetime (25 years) avoided storage costs ($A_{25[el]}$), or $V_{el} = B_{a[el]} * A_{25[el]}$. In considering the potential value added by a UPS function, account is taken of the fact that a DPV-PS system yields, in addition to avoided storage costs, a further benefit in the form of the avoided energy loss (E_{ups} kWh) in comparison to conventional UPS systems. This avoidable loss is assumed to be about 10% of the capacity (kW) of the conventional UPS system, and may be expressed as:

$$E_{ups} = 0.1 * (\text{UPS Rating in kW}) \qquad (4)$$

When multiplied by the utility's energy charge (P), specified in the rate schedule of a given utility, an estimate of the economic value of this energy saving over a period of one year ($E_{1[ups]}$) is obtained using equation 5:

$$E_{1[ups]} = E_{ups} * 8760 * P \qquad (5)$$

The total value added (V_{ups}) to a DPV-PS system by the UPS function is then the sum of the lifetime avoided storage costs ($A_{25[ups]}$) and lifetime avoided energy losses ($E_{25[ups]}$). Thus:

$$V_{ups} = (B_{a[ups]} * A_{25[ups]}) + (E_{25[ups]}) \qquad (6)$$

We applied the above arguments and assumptions to the cost and performance data obtained from 8 vendors and manufacturers of emergency power equipment.

The analysis is based on a roof-mounted, 10kW PV system, with battery storage of 50 kWh (the typical storage requirement found in earlier studies of 10 kW PV systems - see Nigro et al, 1996). The performance of such a DPV-PS system was evaluated for four commercial building types located in the eleven utility territories of the United States. Typical building load profiles for southern and northern climates were analyzed. *PV Planner* was used to conduct present value financial analyses of DPV-PS systems configured to provide peak-shaving as well as emergency power functions. The results are reported in the following section.

MAJOR FINDINGS

Table 1 captures the average results of simulation runs for large and small office, as well as regular and fast-food restaurant load shapes (see Byrne et al, 1997b for a detailed discussion of these results). Data from AEG's utility and commercial clients were used to construct the load shapes.

These results show that North Carolina (Duke Power and Crescent Electric Membership Co.) offers potential for cost-effective DPV-PS system installations. This is due to the 35% renewable energy investment tax credit offered in the state. This, in addition to the 10% federal tax credit, effectively creates a 45% tax savings on capital costs. In fact, benefit-cost ratios greater than or equal to 1.00, were observed for large office buildings and fast food restaurants within the Crescent and Duke utility areas, indicating cost-effectiveness at current installed PV system prices (excluding storage) of $8.70 per Wp (the module price used for these studies - a listing of additional financial parameters is provided in Byrne et al, 1996a).

Table 1: Simulated Average BCRs and Payback Periods for DPV-PS in Selected Utility Jurisdictions

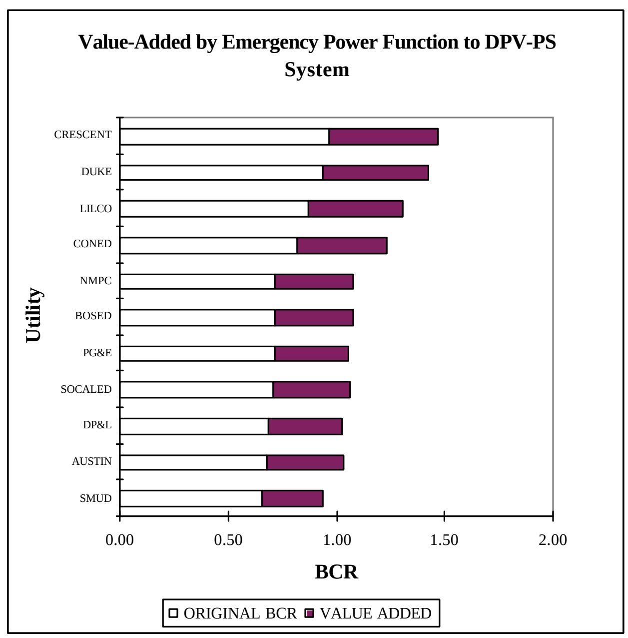
UTILITY	BCR	PAYBACK PERIOD
BOSED (MA)	0.71	30.50
CONED (NY)	0.82	20.06
LILCO (NY)	0.87	15.30
DP&L (DE, MD, VA)	0.68	31.88
NMPC (NY)	0.72	25.50
SOCALED (CA)	0.71	25.61
PG&E (CA)	0.71	26.24
CRESCENT (NC)	0.97	12.75
DUKEPOWER (NC)	0.94	20.37
SMUD (CA)	0.66	36.17
AUSTIN (TX)	0.68	35.87

Office buildings and fast-food restaurants tend to experience peak demand during the daylight hours, thus only modest amounts of storage are required to shift the PV array's output to match the building's peak demand. Also, relatively large variation in electricity demand during afternoon hours reduces the number of dispatch hours needed to achieve significant peak-shaving. These factors tend to make the economics of DPV-PS systems more attractive than for building types with evening peaks and small hourly load variations.

Our analyses of the value added by the EP function included three scenarios involving varying storage requirements to satisfy the EP function: a Low Storage Scenario (where b_f = .01); a Moderate Storage Scenario (b_f = .05) and a High Storage Scenario (b_f = .10). Since the depth of discharge is assumed to be 85%, the storage requirement for EP should be readily met. Results are reported here for the high storage scenario only.

Figure 1 depicts the new BCR values observed when an emergency lighting function is added to the DPV-PS systems. These results suggest that reserving modest amounts of storage capacity (approximately 5 kWh in this case) in a DPV-PS system can increase BCRs by up to 50 percent. This of course manifests as significant reductions in the original payback periods.

Figure 1. Simulated Average BCRs for DPV-PS (EL) in Selected Utility Jurisdictions



The combination of rate structure, tax policy, building type and resource availability appears particularly favorable to the operation of dual-function DPV-PS/EL systems in North Carolina where payback periods of 2 years or less are obtained. Our analyses of DPV-PS systems configured to add the UPS function showed that the value added by UPS is about 17% on average. This is significantly less than the additional value of the EL function for equal amounts of DPV-PS battery power allocated. This is due to the fact that storage cost constitutes a much smaller ratio of total costs of conventional UPS systems. In order to increase the value added to the DPV-PS system, higher allocations of DPV-PS battery storage to the UPS function may be necessary. However, doing this may compromise the peak-shaving function in accommodating a greater UPS capability.

We conclude that, for a 10kW array with typical storage requirements of approximately 50kWh, reserving modest amounts of storage capacity in the DPV-PS system for EP applications can increase the economic viability of such 'dual systems' by significant amounts for building operators.

POLICY IMPLICATIONS

A growing variety of innovative policy options are being used to support renewable energy technologies. We have investigated investment tax credits as one such instrument in which users of renewable technologies can deduct a percentage of the cost of the system from their overall tax liability. This effectively lowers the cost of the system by an amount equal to the investment tax credit.

A sensitivity analysis, conducted for two of the most promising building types - fast food restaurants and large office buildings, suggests that an investment tax credit of 40% to 45% is needed to achieve benefit-cost ratios greater than 1.0 for DPV-PS systems installed on these building types (Byrne et al, 1997b). The corresponding payback periods are less than 10 years. When an EP function is included, several jurisdictions and building types have payback periods of less than 5 years.

CONCLUSION

Our findings can be summarized as follows: (a) At current prices with a tax credit of between 40 and 45%, investments in DPV-PS systems would be cost effective investments throughout much of the US. (b) If an EP function is added, BCRs for DPV-PS systems could be improved by about 17% for UPS applications, and 30 - 50% for EL service.

A DPV-PS system incorporating UPS and EL applications represents an alternative philosophy of energy use which emphasizes service rather than, simply, electrical supply. Existing policy and marketing strategy needs to be re-thought since the aim of the electricity sector (even with deregulation) will largely be to foster supply-side solutions.

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