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PHOTOVOLTAICS AS AN ENERGY SERVICES TECHNOLOGY: A CASE STUDY OF PV SITED AT THE UNION OF CONCERNED SCIENTISTS HEADQUARTERS

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ABSTRACT

This paper presents a technical and economic analysis of the Union of Concerned Scientists' (UCS) 2.1 kW photovoltaic (PV) array located on the roof of their Cambridge headquarters. We analyze the technology from a variety of different perspectives. The system as it currently exists is primarily an energy supply technology. Alternatively, the system could be reconfigured with the addition of a modest amount of storage to serve energy management functions, primarily offering firm, peak-shaving benefits on a daily and yearly basis. This value would be enhanced with better energy management by UCS of their heat pump cycles. We also analyze the economics of the UCS PV array serving an additional emergency power function. The results of our analysis indicate that the economic value of the UCS PV array would be optimized in a configuration that serves all three functions: energy supply, energy management, and emergency power. In fact, we estimate that the payback period for the system configured in this fashion would be approximately five years.

1. BACKGROUND

The Union of Concerned Scientists' headquarters, located in Cambridge Massachusetts, is a showcase of environmentally friendly building technologies. In designing their new office space, which was completed in 1994, the Union of Concerned Scientists demonstrated their commitment to sound stewardship of the global environment. The building incorporates energy efficiency, daylighting, and building-integrated photovoltaics (PV) to create an extremely pleasant atmosphere for employees and visitors.

As part of an ongoing effort, UCS is committed to evaluating the energy performance of their headquarters to demonstrate the long-run economic and ecological benefits of environmentally friendly building designs. As evidence of this commitment, UCS has installed a host of end-use monitoring equipment to better understand how the building's energy systems are performing. In particular, this paper describes an evaluation of the economic performance of the building integrated PV system, a 2.1 kW array installed in 1996 on the roof of the UCS building, and wired directly into the UCS side of the meter. Currently, monitors are collecting data for all eight heat pumps, lighting loads, plug loads, and the building-integrated PV system.

This report is part of the continuing effort to evaluate the energy performance of the UCS headquarters. In particular, this paper describes an evaluation of the economic performance of the building integrated PV system.

2. BUILDING INTEGRATED PV

The evaluation was conducted using load and solar resource data for a one-year period beginning 10/1996 through 9/1997. The technical performance of the PV system in terms of its energy value is stated in monthly kWh savings (i.e., this is energy that does not have to purchased from the local utility). As an energy management technology the performance is evaluated in terms of the monthly peak kW demand reductions. This is consistent with standard impact evaluations of traditional energy conservation and peak-management measures. Table 1 provides the results of this technical analysis when no storage is included.

TABLE 1: PEAK-SHAVING VALUES (1)

Month	Peak-Shaving Values (kW)
January	0.0
February	0.0
March	0.0
April	N/A
May	0.9
June	0.6
July	1.1
August	1.0
September	0.8
October	0.0
November	0.0
December	0.0

Tables 1 and 2 indicate that the system in its current configuration (without storage) is primarily an energy supply technology, providing very little peak-shaving value.

TABLE 2: ENERGY VALUES (2)

Month	Energy Values (kWh)
January	94
February	124
March	159
April	N/A
May	228
June	254
July	247
August	212
September	180
October	162
November	108
December	61

When we explored the building's load profile it was found that spikes occur during the morning hours when there is no available solar resource and thus, no peak-shaving. Figures 1 and 2 illustrate this phenomenon. The spikes can be traced to the fact that the heat pumps cycle on together during the morning hours to heat or cool the building prior to the time when the employees arrive. Through effective energy management this could be altered, thereby enhancing the peak-shaving value of the PV system.

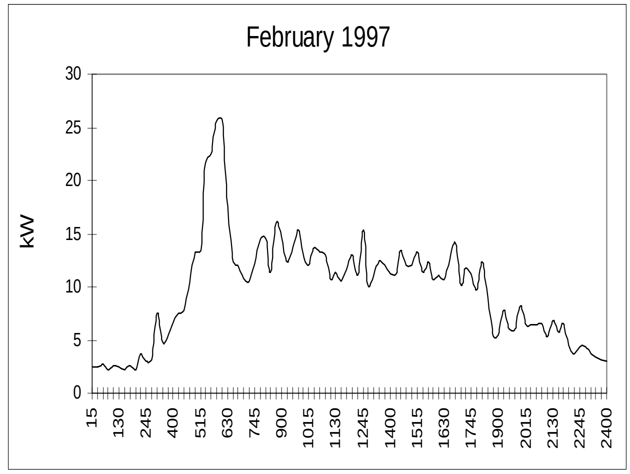

Fig. 1: Building Load Profile February, 1997

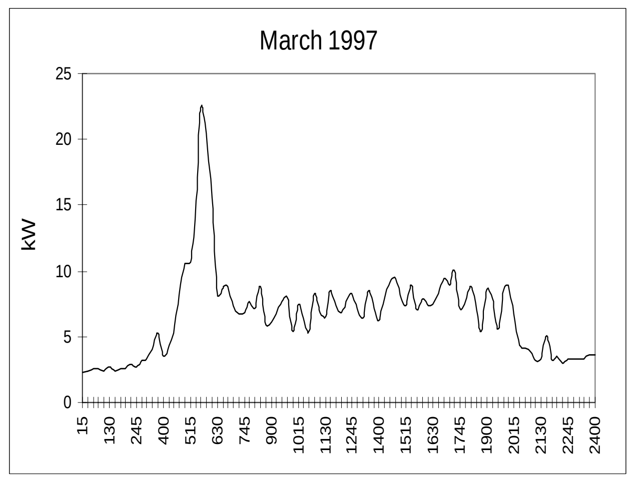

Fig. 2: Building Load Profile March, 1997

This observation is reinforced by the practical experience and concepts developed at the Center for Energy and Environmental Policy (CEEP) which has been investigating the technical and economic feasibility of using PV technology in a number of alternative applications. These include the use of PV as a building energy supply technology (3); an energy management technology (4); and an energy services technology. (5) Such applications offer a combination of benefits that include an energy value (i.e. the system's ability to save energy), a capacity value (in the form of coincident peak demand reduction) and service value (through the provision of emergency power during electrical outages).

To identify applications that allow users such as UCS to obtain the highest overall value from PV technology, a comparative assessment of the value of PV in each of the above-mentioned potential applications is conducted in the sections below. The analysis presented here covers the actual UCS PV system performance.

3. COMPARATIVE ASSESSMENT OF PV SYSTEM CONFIGURATIONS

3.1 PV as a Building Energy Supply Technology

The basic configuration of PV as a building energy supply technology consists of a PV array connected via power conditioning equipment to the building's distribution panel. Because there is no battery storage, the system is referred to as non-dispatchable. In this configuration, PV operates as an electrical energy supply system, complementing the electrical energy obtained from the grid.

Non-dispatchable PV (NDPV) systems shave peak demand based on the output of the system at the time of the building's peak. However, the value of such peak-shaving cannot be reliably estimated and system marketers would be reluctant to guarantee a specific value for this function. There are two reasons for this: (1) significant fluctuations in capacity factor; and (2) an uncertain match between solar insolation and daily building peak. Both points can be illustrated with the UCS PV system. Table 1 shows that, from May through September, the UCS PV system had an average capacity value of 42% of the rated array capacity, but fluctuated from 29% to 76% capacity factor during the peak season. Second, the time during which peak demand is experienced did not coincide with maximum PV output as described in Figure 3 (which shows July 1997 during which the building experienced its summer peak). (6)

For this reason, the peak-shaving value of a building PV energy supply system is treated here as zero. Equation 1 summarizes how the net energy value of the system is estimated. All economic terms have been discounted to reflect the time value of benefits and costs to the building owner. (7)

$$V_E = [O_{pv} * P_E] - C_{pv} \qquad [1]$$

where,

V_E	=	Energy value of PV system
P_E	=	Utility energy charge ($/kWh)
O_{pv}	=	Building PV output (kWh) (8)
C_{pv}	=	Capital and operating costs of the PV energy supply system.

The model in this case assumes that a net metering rule is in place so that the customer can sell all generated energy to the grid at the same rate paid for consumption from the grid. Based on Equation [1], an assessment of the economic performance of the technology from the point of view of UCS was done using PV Planner. (9) The results indicate that the energy value from the system is modest.

Overall, the net present value of -$10,717, benefit-cost ratio (BCR) of 0.58, and the 24 year payback period (exceeding the benchmark figure of 5 years), indicate that, at current capital and operating costs, PV as a building energy supply technology, offers little economic benefit to the UCS.

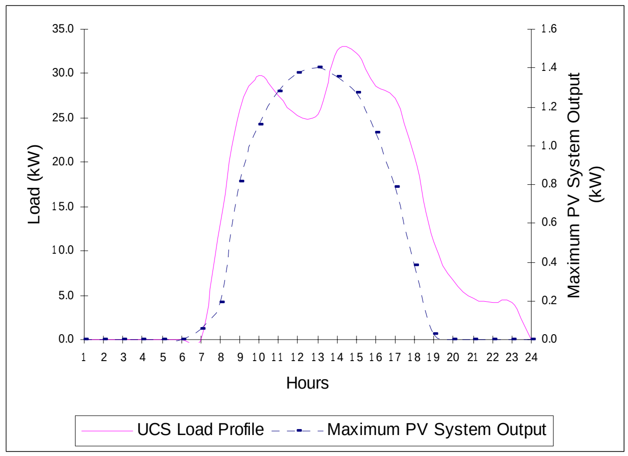

Fig. 3: Comparison of load profile vs. PV system output, July 1997

3.2 PV as an Energy Management Technology

In a second configuration, PV can be used as an energy management device. This requires the addition of modest amounts of storage to the PV array, allowing the system to operate as a dispatchable peak-shaving (DPV-PS) technology [see Figure 4].

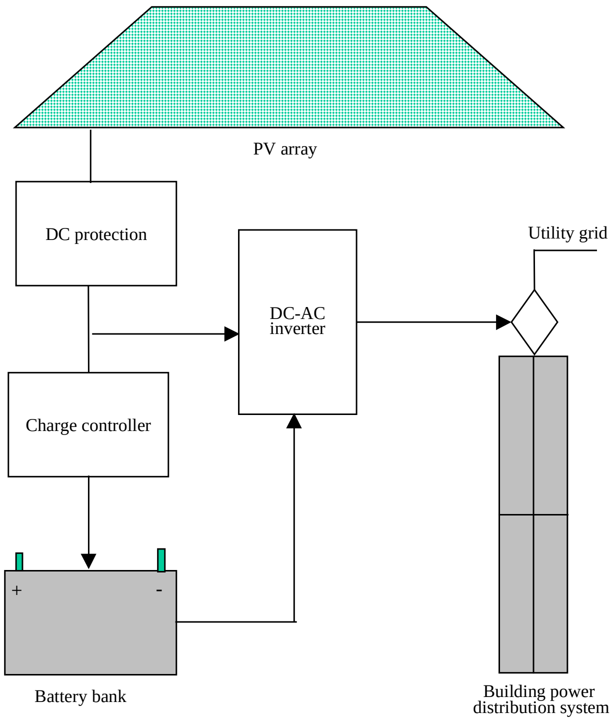

Fig. 4: Conceptual drawing of a dispatchable PV system[a]

[a] A non-dispatchable PV system would not include a battery bank and charge controller.

Source: Center for Energy and Environmental Policy, University of Delaware; Delmarva Power.

Equation 2 estimates the net demand and energy value of the technology:

$$V_M = [P_D(O_{PV} + O_{BAT}) + V_E] - C_{PV} \qquad [2]$$

where,

V_M = Energy management value of DPV-PS system

O_{pv} = PV output at time of building peak demand (kW)

O_{bat} = Battery bank output (net round trip losses) at time of building peak demand (kW)

P_D = Utility demand (capacity) charge

V_E = Energy value as defined in Equation (1)

C_{PV} = Capital operating costs of the PV energy management system.

The O_{bat} term represents the output of the battery bank at the time the building is experiencing its peak demand. It is a function of the size of the battery bank and the number of dispatch hours needed to assure shaving the peak load of the building.

An estimate of the value of PV as a building integrated energy management technology was obtained for the UCS case, again using PV Planner. The net present value of a DPV-PS energy management system is about 7% greater than that of the non-dispatchable energy supply technology. The additional cost of upgrading a PV energy system to perform an energy management function (about $5000) is more than offset by the value added (nearly $5700) in energy management to the customer. A substantial share of this benefit is attributable to demand savings ($3,695) which are significantly higher than energy savings (approximately $2,850). The higher demand saving benefit is explained by the capacity charge levied on customers in large buildings. This charge is typically a much higher portion of electricity billings than energy charges. In the case of UCS, 70% of its electricity billings is for capacity.

3.3 PV as a Building Services Technology

CEEP's recent research (10) envisages the addition of emergency power (EP) functions to the 'traditional' dispatchable PV peak shaving model as a means of further enhancing the overall value of PV. In this section, we describe the basic assumptions underlying the use of PV as an EP technology and estimate the potential value to UCS of such a configuration. Specifically, we have investigated the use of DPV-PS as a source of uninterruptible power supply (UPS) during short-term electrical outages. This UPS function would allow, for example, orderly shutdown of computer and other office equipment in order to avoid costly loss of work completed.

The economic benefit of adding the UPS function to a DPV-PS system is expressed as the *avoided cost* associated with the purchase and operation of conventional UPS systems. In the analysis reported here, it is assumed that the consumer has already identified needs that justify the purchase of a UPS system (which include such balance of system components as inverters and battery storage). For example, at UCS the computers with critical financial, fund raising and donor information must be on all the time. This means that the costs of battery storage, the inverter, and controls are assumed to have already met an economic performance criterion for the building under evaluation. (11) Thus, only the additional capital cost of the PV array (including array structure and installation) must be justified. Accordingly, the payback period for a DPV-PS/UPS system would depend upon the capital costs of the

PV array itself, instead of array costs plus balance of systems costs.

Consistent with the above assumptions, the PV system payback period was determined by subtracting tax credits (if any), annual net tax benefits, annual energy savings, and annual demand savings from the initial cost of the PV array. We believe that this approach is reasonable for a preliminary analysis because the costs of integrated battery/inverter systems are similar to conventional UPS systems. (12)

Equation (3) summarizes the net value of a PV system configured to provide energy management and UPS functions to a building:

$$V_S = [(B_{UPS} - C_{UPS}) + V_M] - \Delta C_{PV} \quad [3]$$

where,

V_S	=	Energy services value of DPV-PS/UPS system
B_{UPS}	=	Customer designated benefits of UPS
C_{UPS}	=	UPS system cost (equivalent to BOS cost of a conventional PV system)
V_M	=	Energy management value of DPV-PS System, as defined in Equation (2).
ΔC_{PV}	=	Additional PV cost (including array structure)

The addition of a UPS function increases the value of a dispatchable PV energy management system on the UCS building. The benefit-cost ratio of this application at the UPS site is estimated to be 1.17. As shown in Figure 5, the payback period is reduced from 19 to 5 years.

These results are consistent with earlier CEEP research which suggested that by reserving modest amounts of storage capacity for UPS in commercial building integrated DPV-PS system, benefit-cost ratios (BCRs) over 1.0 and payback periods under 5 years are expectable (13).

4. CONCLUSIONS

The Union of Concerned Scientists is committed to environmental stewardship. This commitment is demonstrated in the design of their new headquarters located in Cambridge, Massachusetts. The UCS headquarters incorporates a number of environmentally friendly technologies including daylighting, high-efficient energy systems, and renewable energy in the form of a roof mounted photovoltaic system. This paper presents an

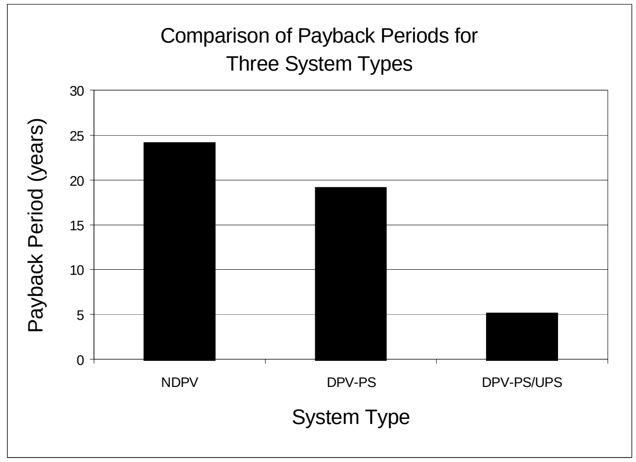

Fig. 5: Payback periods for the UCS system in NDPV, DPV-PS, and DPV-PS/UPS configurations.

analysis of the technical and economic performance of the 2.1 kW PV array located on UCS's headquarters.

Analysis of the existing system indicates that the system is functioning primarily as an energy supply technology. The value to UCS is derived primarily from the PV array's energy output, which reduced the number of kWhs that they must purchase from their local utility. In addition, we identified the need for a somewhat more sophisticated energy management scheme to reduce the morning spikes in the building's demand in an effort to improve the economic performance of the existing PV array.

Thus, one major conclusion from this analysis is the importance of load management to enhance the performance of building integrated PV systems.
PV Planner, a spreadsheet model developed by the Center for Energy and Environmental Policy, was used to evaluate the lifecycle economic performance of the UCS PV array based on three different configurations.

The first analysis focuses on the existing system as it is currently configured as PV only without storage. Second, we analyzed the system in an energy management configuration in which we assume that a modest amount of storage is added to the existing 2.1 kW PV array. In this configuration, the system can offer firm peak-shaving on a daily and yearly basis. Finally, we analyzed the system assuming that it would serve UCS's emergency power needs in terms of protecting valuable information in the event of a power outage. The economic analysis clearly indicates that the economic performance of the UCS system would be optimized if configured to serve all three functions: energy supply, energy management, and emergency power. In fact, we estimate that the payback to UCS would be approximately five years for a system configured in this fashion.

In conclusion, building integrated PV for commercial buildings should be developed in such a way that it serves energy management and emergency power functions in addition to energy supply. Based on our results, it appears that markets may currently exist for building integrated PV configured in this fashion.

5. ACKNOWLEDGEMENTS

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6. ENDNOTES AND REFERENCES

(1) The highest power output observed was 1.6 kW.

(2) The highest daily energy production observed was 97 kWh/day.

(3) Byrne et al (1996) 'Evaluating the economics of phovoltaics in a demand-side management role' Energy Policy 24 (2): 177-185.

(4) Byrne et al (1996) 'Evaluating the economics of phovoltaics in a demand-side management role' Energy Policy 24 (2): 177-185.

(5) Byrne et al (1997) 'Commercial Building Integrated Photovoltaics: Market and Policy Implications' Proceedings of the 26th IEEE Photovoltaic Specialists Conference Anaheim, CA. :1301 – 1304.

(6) The UCS PV array faces approximately 40º west of south. While this orientation was set by physical requirements of the only unshaded space available on the roof of the building, its was also felt that this might provide a better match of the PV array output with the summer peak load demand requirements of the local utility. The resultant shift of PV output toward the afternoon is evident in Figure 3. However, we sacrifice the energy output we would obtain with a true southern orientation, and Figure 3 shows that there is still a mismatch during both early morning and late afternoon periods.

(7) A discount rate of 12% was used throughout the analysis reported here. Although this may be high for an organization like UCS, the results of this analysis are intended to be generalized to commercial building operators with high capital costs.

(8) This refers to output after power conditioning.

(9) PV Planner is a resource-load matching and economic analysis software being developed at CEEP for the National Renewable Energy Laboratory (NREL).

(10) Byrne et al (1997) 'Commercial Building Integrated Photovoltaics: Market and Policy Implications' Proceedings of the 26th IEEE Photovoltaic Specialists Conference Anaheim, CA. :1301 – 1304.

(11) In effect, we are assuming that the building occupant has already reached the decision that UPS is cost-effective.

(12) Results of a survey of UPS vendors (reported by CEEP in May 1997) confirmed that BOS costs of DPV systems are similar to those of typical UPS systems. See Byrne, Agbemabiese and Redlin (1997) 'Evaluating the additional value of emergency power applications in dispatchable PV peak-shaving systems.' Report prepared for the National Renewable Energy Laboratory.

(13) Byrne et al (1997) 'Commercial Building Integrated Photovoltaics: Market and Policy Implications' Proceedings of the 26th IEEE Photovoltaic Specialists Conference Anaheim, CA. :1301 – 1304.