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DEPLOYMENT OF A DISPATCHABLE PHOTOVOLTAIC SYSTEM: TECHNICAL AND ECONOMIC RESULTS

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ABSTRACT

This paper discusses the incorporation of PV as a demand-side management (DSM) tool. The valuation of the benefits provided by PV in a DSM role indicates that it is much closer to commercial viability than was thought from economic analyses focusing exclusively on this technology as a supply-side option. However, in order to realize PV's potential, this technology must be deployed in high-value DSM applications; in particular, applications that promise dispatchable peak-shaving capability. Our analysis of the performance of a prototype system installed by Delmarva Power, indicates that small-scale, commercial customer-sited DSM systems incorporating this technology are approaching competitive cost levels

INTRODUCTION

In many parts of the U.S., utility system peak loads tend to coincide with long, hot sunny days during the summer when high solar insolation is available. The high correlation between utility peak load and the rate of solar insolation has prompted recent interest in DSM applications of PV. [1,2]

Ordinarily, a PV-DSM system's peak load reduction capacity is equal to the power it generates at any point in time. However, an approach integrating PV technology with storage offers the possibility for PV to displace a load greater than its power output at peak demand periods. This application of PV-DSM has been developed by the Center for Energy and Environmental Policy (CEEP) and Delmarva Power (a regional utility serving most of Delaware and portions of Maryland and Virginia). Its practical possibility and economic viability are currently being tested in a project underway at Delmarva Power. Analyses to this point indicate that the combined benefits to customers and utilities are approximately 70 percent of current PV system costs. This places the technology much closer to commercialization than previously thought.

THE CONCEPT OF PV-DSM

The concept of PV-DSM under investigation by CEEP and Delmarva Power differs from those explored elsewhere in that PV technology is deployed in an integrated system design which incorporates some form of energy storage. Most PV-DSM applications are based on maximization of the energy provided by the system to the utility or customer. In contrast, our application seeks to maximize the power which can be made available during a utility's peak demand period. In this design, PV-DSM maximizes demand savings. Such an application could be especially valuable to commercial customers because the rates they pay usually include demand charges which often constitute a far greater portion of their bill than energy charges. A PV-DSM system with storage would maximize the benefits to these customers. At the same time, utilities can benefit from the contribution of PV-DSM systems to peak-shaving.

Demand savings are maximized by designing PV-DSM to offer to utilities dispatchable load-reduction capacity. Dispatchability of a PV-DSM system can be achieved by either integrating the solar component with a direct load control device or by incorporating some form of energy storage. [3] Possible forms of storage include batteries and cool storage (e.g., for a system designed to manage air-conditioning loads).

The PV-DSM system analyzed below uses batteries to store the energy produced by the PV system during periods of relatively low demand (early to mid-morning). By sizing the battery bank so that it can be comfortably charged by the morning sun available in a peak demand day (this can be done by sizing on the basis of a "worst case" peak demand day), the system can deliver dependable dispatch capacity to utilities. For example, a system incorporating a 10 kw PV array and 50 kwh of battery storage can consistently provide 16.3 kW of power for a four-hour period in the Mid-Atlantic.

An alternative to PV-DSM which can provide dispatchable peak shaving capacity is a battery only system. Such a system would utilize off-peak, base load generating units to charge a bank of batteries. The stored energy (minus round trip losses) would then be available for peak load dispatch. But a dispatchable PV system is conceptually a better an option than the battery only system because: 1) the fuel costs for a PV unit are zero, and, therefore, investment risks associated with fuel costs are eliminated;

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2) battery systems must purchase energy and a portion of that energy is wasted due to round trip losses; 3) the PV array, as well as its battery unit, supply energy at the time of dispatch, thereby reducing storage requirements and associated hazards and costs; and 4) joint deployment of a PV array and battery storage requires only one inverter per system.

The system depicted in Figure 1 identifies the major components: the PV array, DC interface, battery/inverter module and control module. The system at Delmarva Power was designed for summer peak shaving using the combined output of the PV array and energy in short-term battery storage. Based on data taken during the Summer of 1992 in tests at the University of Delaware and data collected during system testing from July through September 1993, clouds are practically non-existent on the summer days in which Delmarva experiences system peaks. On such days, the output of the PV array is evenly divided between morning and afternoon, peaking at solar noon (approximately 1:00 PM, DST). However, Delmarva's need for capacity, like many other utilities, is skewed towards the afternoon hours. To meet the problem, the array's output during the morning hours was used to charge a battery bank. This stored energy, minus storage losses, was combined with the array's output in the afternoon and fed into the building's distribution grid. The system's capacity is dependent on the amount of energy stored prior to dispatch, and the duration of the dispatch period.

Table 1
Dispatchable PV-DSM System Description

Site:DP&L Northern District General Office, Newark, DE	
Flat roof mounted array, ballast tray configuration	
Fixed flat plate array of Cz silicon based modules	
PV Array DC Rating:	14.5 KW (PVUSA Conditions)
Storage Capacity:	25 kwh @ 4 hr discharge rate
Inverter:	31.25 kw Omnion inverter
System Output:	480 VAC 3 phase

SYSTEM DISPATCH PERFORMANCE

The primary purpose of the Delmarva Power system is to test the practicality of dispatchable PV. The system was dispatched a total of 27 times from July through late September 1993. An example of a "back-to-back" dispatch is shown in Figure 2. This represents the most difficult design condition for the unit, because it requires the batteries to be fully charged in time for the peak-shaving on successive peak days. This ability of the system to be reliably dispatched on successive days is a function of the availability of solar energy for battery charging on system peak days.

The performance of the system during dispatches and charging cycles helped to highlight a few of the problems associated with hardware components (i.e., control system, battery storage capacity, and PV array performance), but also established the soundness of the

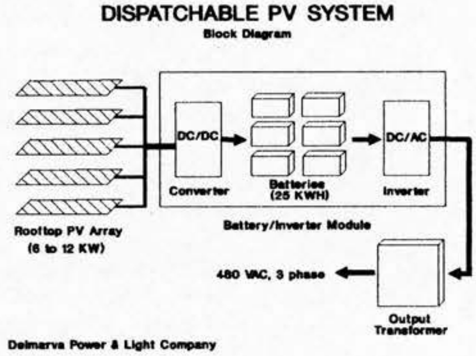

Figure 1

basic concept. This is a major step forward because this type of system was never actually tested before the Summer of 1993. Refinements are now being made for a commercially viable system by summer 1995.

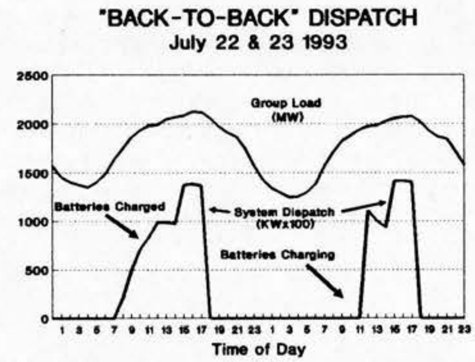

Figure 2

SOLAR RESOURCE AND SYSTEM SIZING ANALYSIS

Solar resource availability on system peak days is an important factor in the operation of the dispatchable PV system. Because the system uses storage, it is not important that the solar resource and load coincide exactly. In Figure 3, the coincidence between Group Load and Global Horizontal Irradiance is shown for the highest hourly loads during the month of July 1993. Although the coincidence is good for about the ten highest load hours, it drops quickly. The main implication of this is that the effective load carrying capability of a PV array without storage in this region is significantly smaller than the nameplate rating for all but a few hours.

Figure 4 shows the coincidence between Total Daily Solar Energy Availability (expressed as kWh/day/sq. meter) and Daily Peak Loads for weekdays from July through September 1993. Because the trends shown are nearly parallel, this figure indicates that, for about the 20 highest summer peak loads, there is a high and relatively predictable level of solar energy available on those days.

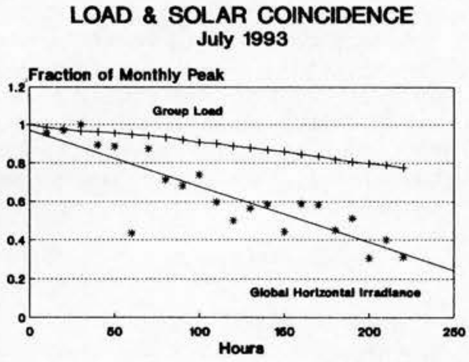

Figure 3

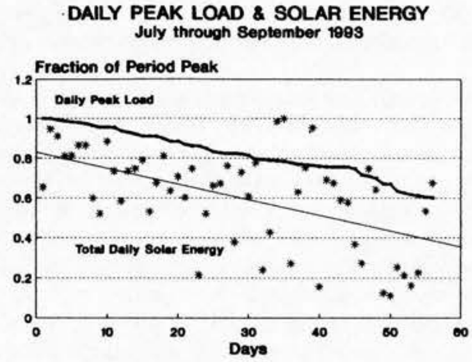

Figure 4

Because the hottest days in the region are also quite humid, the amount of solar energy actually available is somewhat lower than the clearest, cooler, low humidity days. For lower utility loads, the data indicates less predictability. This is because cooler summer days in the mid-Atlantic region (also days in which utility loads are lower) are a mixture of cloudy and very clear sunny days. This figure has a direct impact on the design of dispatchable PV systems because it indicates the relative quantity of solar energy available for collection and storage on peak days.

A combination of PV array and battery storage component performance, resource availability data, and reasonable design assumptions can be used to help size dispatchable PV peak shaving systems. A methodology which accomplishes this would first establish the number of times peak shaving is required during peak months, and then optimize the PV array size for the expected solar resource relative to a given increment of battery storage capacity. This methodology is presently under development at Delmarva Power.

ECONOMIC ANALYSIS OF DISPATCHABLE PV-DSM PEAK SHAVING SYSTEM

The net present values (NPV) of benefits and costs for a 10 kW dispatchable PV peak-shaving system with a 25 year life were calculated using a PV-DSM model developed by CEEP and Delmarva Power, see [2]. With ground source global-horizontal irradiance data supplied by a University of Delaware test facility, it was estimated that the AC output of a 10 kW PV array dispatched daily for four hours during Delmarva's peak demand would typically be credited with a peak-shaving capacity of 16.3 kW during the summer months. Battery storage size was determined by identifying the maximum kwhs generated from 7:30 am until 1:00 pm, using a dispatch period of 2:00 - 6:00 pm for the dispatchable PV-DSM system. The nominal battery storage was 50 kWh.

PV-DSM's benefits and costs were calculated for utility and customer owned systems. Table 2 summarizes the NPVs of benefits and costs for each ownership option. Neither a utility or customer owned system passed the benefit cost test where a value of 1.0 or greater indicates cost effectiveness.

The NPV costs for the utility are made up of three components: capital costs, operating and maintenance (O&M) costs, and carrying charges. Capital costs include $8,500 per kW for the PV array and inverter and $200 per kWh for battery storage. O&M costs include $500 every five years for overhauling the power conditioning system and $150 per kWh every seven years for battery replacement. Delmarva Power current carrying charges

Table 2
Benefit Cost Comparison: 16.3 kW (Credited Capacity) Dispatchable PV-DSM for Delmarva Power

Benefits ($)		Costs ($)	
Utility Owned and Operated			
Avoided Costs	45,690	Capital Costs	95,760
Environmental Benefits	170	Carrying Charges	25,930
Tax Savings	50,340	O&M Costs	24,340
Total	96,200		146,030
Benefit Cost Ratio	0.66		
Customer Owned and Operated			
Energy Savings	9,350	Capital Costs	95,760
Demand Savings	18,260	O&M Costs	15,870
Tax Savings	57,280		
Total	84,890		111,630
Benefit Cost Ratio	0.76		

The utility discount rate: 7.99%, the customer discount rate: 12.0%

were used to cover annual requirements for allowable return, taxes, depreciation, and other fixed overhead costs.

Customer ownership and financing of the PV-DSM system yields a higher benefit cost ratio. Under this ownership option, the customer would retain all bill savings that result from the operation of the PV-DSM unit. Tax benefits include the deductibility of depreciation (on a double declining balance basis) and interest payments and a 10 percent renewable energy tax credit on the purchase of the PV-DSM system. Customer NPV costs include the same capital and O&M costs described above in the utility ownership option. The NPV of O&M costs differ because the customer has a higher discount rate (12%) than the utility's. It is assumed that the customer would not attach carrying charges to this investment. The combined benefits to customers were found to be 76 percent of system costs.

SENSITIVITY ANALYSIS

The above cost-benefit analysis indicates that commercialization of this system is within grasp. Several cost/benefit trials were conducted to assess the sensitivity of the cost/benefit ratios to key assumptions used in the calculations. There are three factors which are the most leveraging. These are array efficiency, system cost and the ownership financing method.

The PV array DC efficiency (at PTC - PVUSA Test Conditions) for the base case was taken as 10.24%. This value was assumed based on measured array values for the Delmarva system. An increase in the array efficiency to 12.24% changes the benefit cost ratio to 0.81. This change assumes that the system (array plus inverter) cost at $8,500/kW is fixed. The increase in benefit cost ratio is due to the increase in the value of the electricity generated for a fixed credited capacity and a reduction in capital cost.

Changing the PV array plus inverter part of the system cost from $8,500/kW to $4,500/kW produces an increase in the benefit cost ratio to 0.87. The change is not as great as might be anticipated because of the effect of tax benefits from capital investment. As the total system cost goes down these benefits decrease commensurately.

The key assumption which influences the benefit cost feasibility for dispatchable PV systems is the basis for ownership of the system. Calculations in Table 2 limit the benefit according to those for the customer or the utility, but not both. If we assume a joint ownership of the system, as described in [3], the utility value for dispatchable peak shaving and the customer value for reduced energy costs can be combined. Such an approach depends on the avoidance of double counting of benefits. This has been addressed in what is elsewhere discussed as a Green Investment Fund (GIF). The benefit cost ratio for a GIF in Delmarva Power's service territory would be 0.92 under the same system used for the calculations in Table 2.

In sum, to speed commercialization, increases in system efficiency, reductions in system cost and joint ownership options need to be pursued. This analysis shows that modest improvements in the cost and performance characteristics of PV-DSM systems as well as expanded ownership options will make these systems cost effective in the Mid-Atlantic region (an area with only moderate solar isolation levels).

CONCLUSIONS

Our analysis suggests that PV-DSM is technically feasible and near commercial viability. In the case of a dispatchable PV-DSM application, the benefits generated by this option equal 76 percent of the current costs for an installed, customer owned system. By reducing costs, and improving the efficiency of major PV system components, as well as employing joint ownership options, dispatchable PV systems could soon emerge as cost-effective DSM options for commercial buildings. The introduction of environmental and fuel risk factors into utility calculations and continued movement toward real-time electricity pricing will all enhance the competitiveness of the PV-DSM application discussed here. The benefits made possible by the application of PV in a DSM role are considerable and place photovoltaic technologies much closer to large market penetration than is conventionally assumed.

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REFERENCES

[1] B. Bailey, J. Doty, R. Perez and R. Stewart., "Performance of a Photovoltaic Demand-Side Management System", *Proceedings of the 1991 ISES Solar World Congress*, 1991.

[2] T. Hoff, H. Wenger, D. Keene., "Photovoltaics as a Demand-Side Management Option", *Pacific Gas & Electric, Research and Development , Report 007.5-92.4,* 1994.

[3] J. Byrne, Y-D. Wang, R. Nigro and W. Bottenberg., "Commercial Building Demand-Side Management Tools: Requirements for Dispatchable Photovoltaic Systems", *Proceedings of the 23rd IEEE Photovoltaic Specialists Conference.* Louisville, KY, 1993, pp 1140 - 1145.

[4] J. Byrne, Y-D. Wang, R. Nigro, and S. Letendre., "Photovoltaics in a Demand-Side Management Role", *ACEEE 1994 Summer Study on Energy Efficient Buildings, Proceedings*, 1994, pp 2.43 - 2.48.