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PERFORMANCE OF A PHOTOVOLTAIC DEMAND-SIDE MANAGEMENT SYSTEM

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ABSTRACT

This paper presents an analysis of experimental data for a building retrofit, roof-mounted photovoltaic array conceived as a demand-side management (DSM) system. Our analysis focuses on 1) assessing the technical performance of the photovoltaic system and its components; and 2) assessing its load-matching and DSM capability.

KEYWORDS

Demand reduction; demand-side management; load matching; peak shaving; performance; photovoltaics; power quality; utility applications.

INTRODUCTION

Recent studies have indicated that photovoltaic energy production is well correlated with the electrical power needs of selected large commercial utility customers, especially when their load is driven by a daytime demand for air conditioning (Perez and others, 1989). Photovoltaics can effectively contribute to meeting the peak power requirements of these customers, while providing demand relief to the utility. Hence, opportunities may exist for the deployment of PVs as demand-side management (DSM) systems (Perez and Stewart, 1988).

With this potential in mind, the Niagara Mohawk Power Corporation in 1990 commissioned a 15.4 kW (DC) prototype PV array on a state-owned building near Albany, NY. The goal of this project is to study the value of photovoltaics as a DSM option for commercial customers within its service territory (Bailey and others, 1990). This paper reports on the PV system's performance during its first six months of operation and assesses its load matching capability.

SYSTEM DESCRIPTION

The PV array was installed on the existing roof of the building that houses the headquarters of the New York State Division of Military and Naval Affairs (DMNA). The building is of recent, energy-efficient construction. It operates primarily under a daytime administrative schedule, although military drill activities occur every Tuesday evening.

The PV system has the following characteristics:

Modules: 70 polycrystalline ribbon silicon flat-plate panels (Mobil Solar Ra180).

Module Area: 151 sq. m.

Structure: 3 passive one-axis trackers (Robbins Engineering) with horizontal N-S axis and horizontally mounted modules.

Inverter: High efficiency 15 kW power conditioning unit (PCU) with maximum power point tracking capability (Omnion Series 3200).

Interconnect: Customer-side-of-the-meter utility connected electrical distribution system (3-phase 480 V).

The system began operation on schedule in late June 1990.

A data acquisition system polls over 50 sensors every 10 seconds and records 10-minute averages. Measurements include meteorological and insolation conditions, array temperature and orientation, array output, inverter performance, power quality, and customer demand.

SYSTEM PERFORMANCE

We are interested in two specific aspects of the system's performance: 1) technical and 2) demand reduction. Technical performance pertains to system as well as to component reliability and the meeting of design expectations, while demand reduction performance applies to the system's ability to meet its load matching objective. The latter depends on two time dependent variables -- the solar resource and the building load -- while the former is mainly technology dependent.

Technical Performance

Tracking: Our results indicate that the passive trackers lag by an average 5^{o} ($\sigma = 3.5^{o}$) behind the sun's position, except for early morning points when the array goes sunward from its near horizontal "sleeping" position. Figure 1 is a plot of the observed difference between the measured array slope and the optimum slope for clear sky conditions. The trackers tended to be slower in "waking up" and in tracking the sun during cold ($<0^{o}C$) weather.

Modules: The conversion efficiency of the modules is compared to that which would be expected from the manufacturer's specifications. Table 1 lists the ratio of measured vs. theoretical DC power as a function of the level of irradiance impinging on the modules. Theoretical DC power was obtained by derating the array output as a function of measured operating temperature, per manufacturer's specifications. The clear day ratio is approximately 95% which, after accounting for line loss and instrument uncertainty, is very acceptable. Note that this ratio is dependent on the ability of the inverter to maximum power track; the inverter is probably responsible for some of the degradation at low intensity.

Inverter: The DC to AC conversion efficiency is reported in Table 1 as a function of available irradiance. It is also plotted in Fig. 2 as a function of AC output. Efficiency exceeds 90% when the inverter operates above 25% capacity. The inverter operates at a power factor of 0.98 over most of its operating range, as seen in Fig. 3. In terms of power quality, the total harmonic distortion of the current produced was found to be less than 10% when the inverter operates at 50% capacity, and is estimated to be 5% at full power; this will be confirmed by further tests during summer 1991. The total harmonic voltage distortion is under 3% and is relatively unaffected by power level.

System Availability: Since startup, the system has been operating 93% of the time with 3% downtime traced to the inverter, 1% to the array and 3% to project R&D (e.g., sensor installation, design modifications, etc.).

Other Remarks: Table 1 also reports on overall system efficiency (a) based on a constant array rating of 15.4 kW and (b) accounting for the expected effect of module temperature. The noticeable differences show the importance of properly defining the expectations of an operating PV system (Bailey and others, 1990). In our opinion an "operative" rating accounting for the critical operating temperature (in the present case, that of a summer heat wave), and also for expected DC to AC conversion losses, would be more helpful to the industry than the current practice.

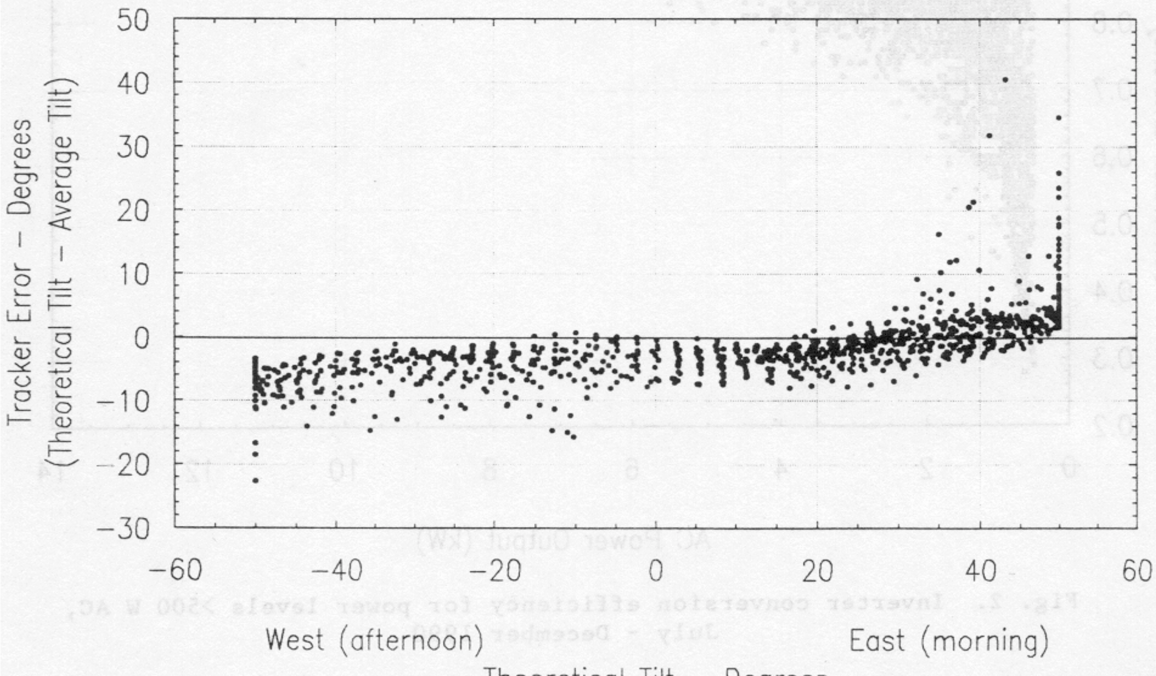

Fig. 1 Average diurnal tracker error for POAR >750 W/m^2 and beam >500 W/m^2, July-December 1990

TABLE 1 Mean Conversion Efficiencies - July-December 1990

Eff.	All Values	POAR ≥ 250	POAR ≥500	POAR ≥750
B/A	0.952	0.941	0.923	0.898
C/A	0.853	0.861	0.864	0.851
D/A	0.765	0.779	0.789	0.784
C/B	0.896	0.914	0.936	0.948
D/B	0.803	0.827	0.855	0.874
D/C	0.896	0.905	0.914	0.921
Mean Array Temperature (^{o}C)	26.1	33.3	39.0	45.4

A -> Theoretical DC Power (uncorrected for temperature)
B -> Theoretical DC Power (corrected for temperature)
C -> Measured DC Power
D -> Measured AC Power

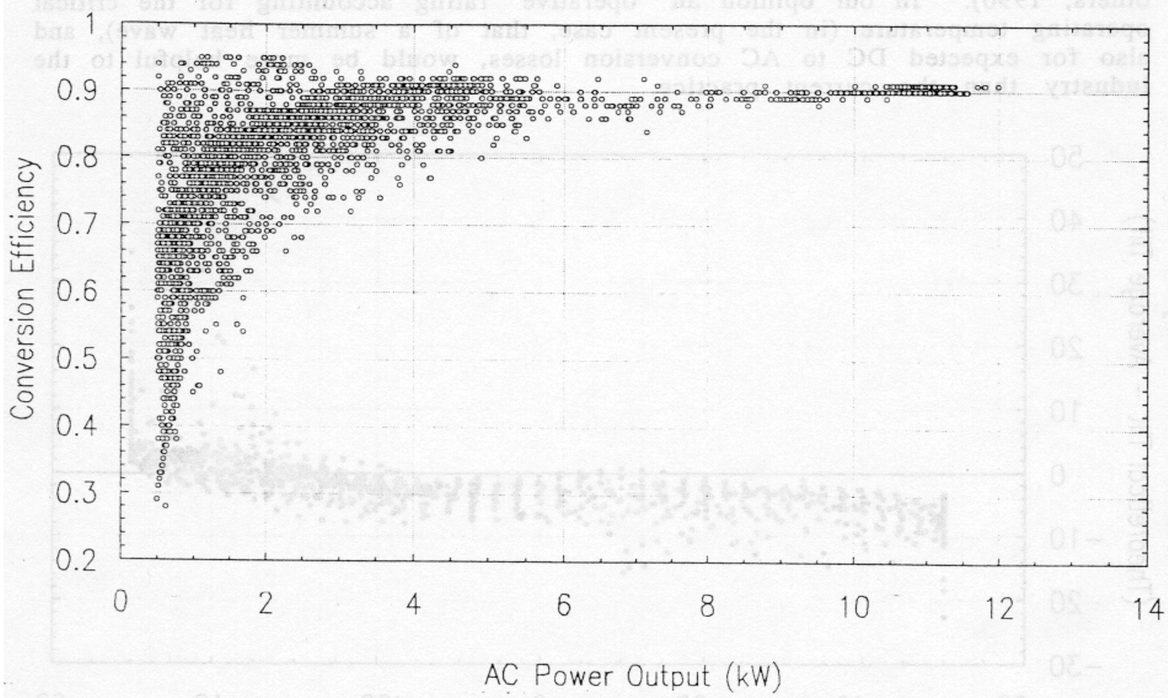

Fig. 2. Inverter conversion efficiency for power levels >500 W AC, July - December 1990

Demand Reduction Performance

Figure 4 illustrates the behavior of the PV system during the most critical week of the 1990 summer when the building reached its peak demand. We have purposely increased the array yield by a factor of 10 in this example, since this is representative of the size a building of this type could easily accommodate. Results indicate that the PV energy is well in phase with demand and effectively shaves the daily peaks. In more quantitative terms, the DSM capability can be measured by the system's availability at the times of highest demand. These results are detailed in Table 2. Availability is provided both in terms of fixed DC rating and "operative" AC rating as explained above. Since system startup the mean operative availability in terms of AC rating for the ten highest 10-minute loads has been 73%; for the 50 highest, it was 68%.

Another measure of DSM capability is the determination of the minimum buffer storage necessary to guarantee that the building load will never exceed a given threshold (Perez and others, 1991). Our experience is very positive in this respect, since it shows that a properly sized array for this building would have required less than 2 hours of storage to reduce the peak demand by 10%. By contrast, a stand-alone storage-based DSM system would have required 4 times more to accomplish the same reduction.

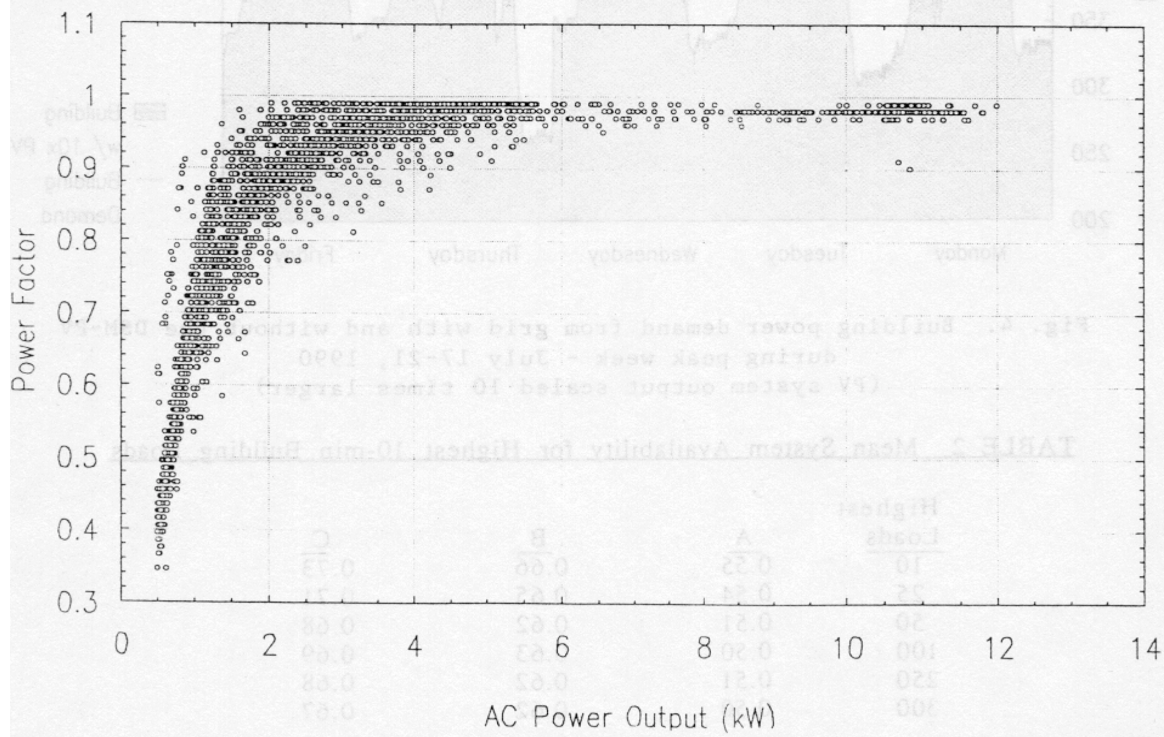

Fig. 3. Inverter output power factor as a function of AC output

CONCLUSION

Based on the first six months of operation, we report that the system has met its major objective: that of demonstrating its DSM capability in the field. Technically, we were pleased by the reliable operation of the system, as well as the minimal maintenance that has been required. System operation and monitoring is scheduled to continue through the summer of 1991.

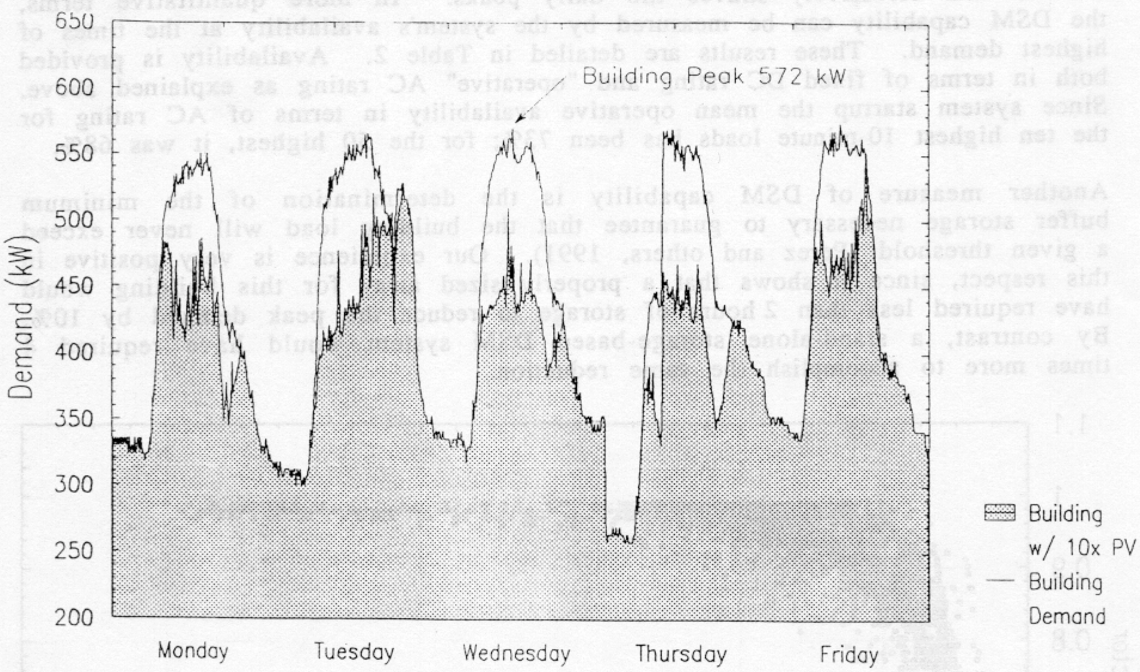

Fig. 4. Building power demand from grid with and without the DSM-PV during peak week - July 17-21, 1990 (PV system output scaled 10 times larger)

TABLE 2 Mean System Availability for Highest 10-min Building Loads

Highest Loads	A	B	C
10	0.55	0.66	0.73
25	0.54	0.65	0.71
50	0.51	0.62	0.68
100	0.50	0.63	0.69
250	0.51	0.62	0.68
300	0.50	0.62	0.67

A - AC output vs. 15.4 kW DC rated capacity at 25°C panel and 1000 W/m^2

B - AC output vs. theoretical AC capacity at 1000 W/m^2, corrected for actual panel temperature

C - AC output vs. theoretical AC capacity at 30°C ambient temperature and 1000 W/m^2

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