

ESTHETICALLY DESIGNED MUNICIPAL PV SYSTEM MAXIMIZES ENERGY PRODUCTION AND REVENUE RETURN

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ABSTRACT

In late 2008, the City of Sebastopol, CA installed a unique 42 kW grid-interactive photovoltaic (PV) system to provide electricity for pumps of the Sebastopol municipal water system. The resulting innovative Sun Dragon PV system, located in a public park, includes design elements that provide optimized electrical performance and revenue generation for the energy produced while also presenting an artistic and unique appearance to park visitors. Early results indicate that the system design does maximize revenue value from the on-site electricity generation through matching of peak energy with the time-of-use tariffs in place for this large electrical load. Results are presented showing system production and time coincidence with high value peak tariff rates. In addition, the 15' high, 11' wide and 365' long system is at home in this park setting with interesting appearance and broad acceptance by the public.

The City of Sebastopol through its Solar Sebastopol initiative received a California Air Resources Board grant to form Solar Sonoma County. Solar Sonoma County in conjunction with the City of Santa Rosa and the other nine municipal governments in Sonoma County participate in the Solar America Cities program sponsored by the U.S. Department of Energy.

1. INTRODUCTION

The City of Sebastopol is a municipality of 7,500 residents located in Sonoma County, California, roughly 60 miles north of San Francisco and 7 miles inland from the Pacific Ocean. Sebastopol is an environmentally proactive community so, eight years ago, the town's City Council voted to fund a program called Solar Sebastopol. The program's mission was to educate the public and encourage the adoption of solar technology by private home owners, business and government. Privately and publicly, over 800 kW of PV has been installed within city limits, 250 kW of

which are operated on municipal facilities. Current estimates are that PV provides 3% of all energy used within the City and comprises as much as 20% of all energy used by municipal buildings and facilities. Solar Sebastopol proved so successful that it has now evolved into Solar Sonoma County to spread its success countywide.

In 2008, the City solicited proposals for PV systems at a number of locations including the municipal well located in the area known as Spooner Park. The park area has a number of large trees and is used for display of artwork during the City's annual Sculpture Jam. The City chose a design compatible with this highly visible location that included a ground mount array on steel poles designed by architect, Katherine Austin, AIA. The design included unique features that made it esthetically appealing while simultaneously maximizing the energy production during the times of the day when electric energy is most expensive. This combination of attractive design and practical engineering served both the city's desire for an artistic addition to the park and its large, water pumping energy requirements.

2. PHOTOVOLTAIC SYSTEM DESIGN

The design of the array utilizes 36 subarrays mounted on 36 poles. The subarrays were installed with varying tilt angles selected to maximize the energy production of the array but to stagger the time of maximum production to coincide with the time based rate structure of the electric utility. The existing water pumping station load is fed from the Pacific Gas and Electric (PG&E) power grid and billed according to time of use rates. Under this tariff, energy costs are greatest when purchased during daylight (on-peak) hours and least when purchased during night time (off-peak) hours. The value of on-peak energy is almost four times the value of energy during off-peak periods. The subarrays are tilted at 6 different angles to capture maximum solar incidence at different times throughout the day, coincident with on-peak

operation. In addition, careful row to row shading analysis was performed to afford the closest possible spacing between subarrays. Only coplanar subarrays are combined electrically as strings, thereby eliminating any mismatch due to incidence angle differences. The system utilizes 6 different inverters, with separate maximum power point tracking. Strings are combined at different angles to obtain maximum production throughout the day while minimizing inverter clipping. On an annual basis, modeling has shown that this 42 kW system will produce 73.5 MWh of energy annually. Critical to the economics of the system, over 70% of the energy produced by the system occurs during expensive on-peak or partial-peak periods.

3. PHOTOVOLTAIC SYSTEM ESTHETICS

The PV array design chosen for this highly visible park presents an innovative appearance to people passing through this well-travelled part of the City. The array (Figure 1) is mounted on a linear arrangement of thirty-six poles. The

design utilizes panels oriented at six varying tilt angles to suggest an undulating movement to these static structures. The poles have circular screening to support climbing vines which will be planted in the spring.

4. PHOTOVOLTAIC SYSTEM ECONOMICS

Favorable economics for the Sun Dragon PV system arise from the combined effects of a zero interest loan for the purchase price, receipt of performance based incentives for the renewable energy produced, and leveraging of expensive utility energy produced at peak times and consumed at lower rates during off peak times.

Table 1 presents the economics and cash flow modeled for the Sun Dragon PV system. The financing mechanisms used for this system couple with the high value production of energy during utility peak periods to result in a project with positive cash flow from year 1 on.



Fig. 1: City of Sebastopol, CA, Sun Dragon Photovoltaic Array (note: varying subarray tilt angles along length of the array for both time-of-use production and esthetics, the poles have circular screening to support climbing vines)

TABLE 1: SUN DRAGON PV SYSTEM ECONOMICS AND CASH FLOW

Year	1	2	3	4	5	6	7	8	9	10
Cash Inflow										
Generation Value	16,000	16,960	17,978	19,056	20,200	21,412	22,696	24,058	25,502	27,032
PBI payments	21,000	21,000	21,000	21,000	21,000					
Total Cash Inflow	37,000	37,960	38,978	40,056	41,200	21,412	22,696	24,058	25,502	27,032
Cash Outflow										
CREBS payments	(27,100)	(27,100)	(27,100)	(27,100)	(27,100)	(27,100)	(27,100)	(27,100)	(27,100)	(27,100)
Maintenance	(800)	(848)	(899)	(953)	(1,010)	(1,071)	(1,135)	(1,203)	(1,275)	(1,352)
Total Cash	(27,900)	(27,948)	(27,999)	(28,053)	(28,110)	(28,171)	(28,235)	(28,303)	(28,375)	(28,452)

Outflow										
Annual Cash Flow	9,100	10,012	10,979	12,003	13,090	(6,759)	(5,539)	(4,245)	(2,874)	(1,420)
Cum Cash Flow	9,100	19,112	30,091	42,094	55,184	48,425	42,886	38,642	35,768	34,348

The City of Sebastopol purchased the Sun Dragon PV system using Federal Clean Renewable Energy Bonds (CREBS). CREBS were created as part of the Energy Policy Act of 2005 (EPACT 2005). CREBS are “tax credit” bonds in which the interest is paid by the Federal Government in the form of a tax credit. CREBS provide a subsidy for municipalities to invest in renewable energy and act as an interest-free loan to the borrowing municipality. With CREBS, the principal repayments are amortized annually and equally over the length of the term. The principal must be repaid within 16 years.

The City of Sebastopol will also receive the State of California Performance Based Incentive (PBI) for energy produced by the Sun Dragon System. The California Solar Initiative offers two possible incentive mechanisms, Performance Based Incentives (PBI) and Expected Performance Based BuyDown (EPBB). PBI is based on actual production and the rate for the Sun Dragon is \$0.32 per kWh produced over the first five years of operation. The EPBB is an estimate based on the capacity as calculated by PVWATTS II and interoperated by the California regulatory process. EPBB payments are set at a fixed rate per watt. Modeling for this system showed that PBI incentives would yield about \$40,000 more in payments than the EPBB single payment. These estimates indicate that PBI will provide over \$100,000 of state incentive funding to defray the cost of purchasing the system.

Lastly, this municipal water pump load operates under a commercial time-of-use tariff (Pacific Gas and Electric tariff A-6) in which energy needed for pumping during on-peak, daylight hours can cost up to four times more than as energy purchased during off-peak periods. Table 2 shows the tariff structure for this municipal water pumping load.

TABLE 2: TIME OF USE TARIFF (PG&E A-6)

Summer	Time	Day	Rate
Peak	12:00pm – 6:00pm	M-F	\$0.41487
Part Peak	8:30am-12:00 pm and 6:00pm -9:30pm	M-F	\$0.18872
Off Peak	All other times		\$0.11732
Winter			
Part Peak	8:30am – 9:30 pm	M-F	\$0.14196
Off Peak	All other times		\$0.11603

Producing energy from the PV system during on-peak hours avoids the purchase of this expensive energy. Modeling for this system indicates that over 70% of the energy produced will occur during on-peak or partial-peak periods. Figure 2 shows the modeled production for the Sun Dragon system indicating the time coincidence of most of the energy produced with on-peak and partial-peak hours of the day.

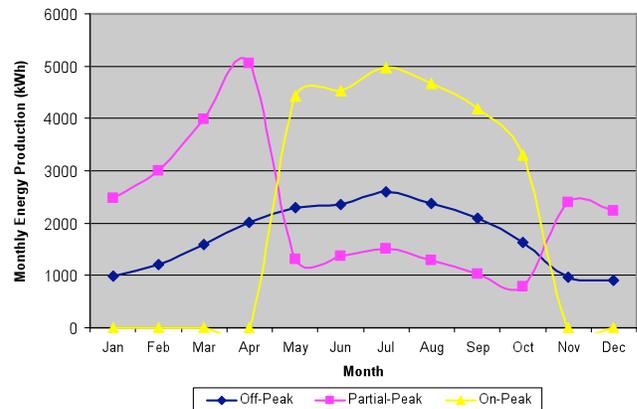


Fig. 2: PV System Energy Coincidence with Peak Utility Rate Periods throughout the Year.

3. MEASURED SYSTEM PERFORMANCE

The Sun Dragon PV array consists of 288 Mitsubishi PV-UD180MF5 PV modules mounted on thirty-six poles at five different tilt angles: 20 degrees, 24 degrees, 28 degrees, 32 degrees, and 36 degrees. Table 3 shows the number of modules mounted at each tilt angle. The system uses six SMA 7000U Sunny Boy inverters.

TABLE 3: NUMBER OF MODULES AT EACH TILT ANGLE

Subarray Tilt Angle	Number of Modules
20 Degrees	96
24 Degrees	128
28 Degrees	128
32 Degrees	128
36 Degrees	96

The system has been operating since January 2009. Recorded production data for 9 March 2009 are presented in Figure 3. In the figure, the system is seen to “wake up” and

begin operating just after 7:30 a.m. relying entirely on diffuse light thanks to the arrays high string voltages. The prominent feature of the day's production graph is the clipping of maximum power observed during most of the mid-day hours. The combination of high solar irradiance and cool ambient temperatures resulted in maximum output from all six inverters which are designed to limit their production to their rated power. In the hot summer months, these inverters will operate below this limit, maximizing mid-day summer energy production.

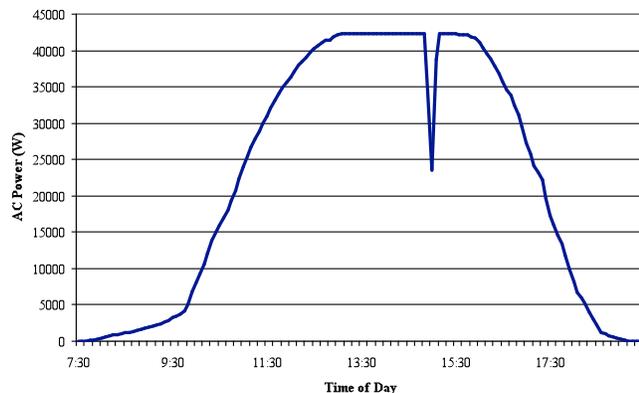


Fig. 3: Sun Dragon PV System Production for 9 March 2009. Note the annoying cloud.

4. ACKNOWLEDGMENTS

The U.S. Department of Energy's Solar America Cities program provided support to the authors of this paper through contract DE-FG36-05GO15149.