AEC PHOTOVOLTAIC TEST FACILITY – FIRST YEAR TEST DATA

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ABSTRACT

Alternative Energy Consortium's Photovoltaic test facility (AEC PV) came on line in August, 2004. System monitoring, using Fat Spaniel Technologies software was installed in December 2004. In May, 2005, the University of Oregon Solar Radiation Monitoring Lab (UO SRML) under a contract with the Energy Trust of Oregon, installed additional monitoring equipment at the site, expanding the number of monitoring points and providing a means to collaborate the information collected by the Fat Spaniel monitoring system. Information was gathered in the first year of monitoring about component efficiencies, system monitoring and system loading that can be applied to future installations.

1. INTRODUCTION

The purpose of the test facility is to evaluate different photovoltaic products and to monitor the performance of these products under different environmental conditions. The test facility consists of a 25 KW rooftop array separated into eight systems. Each system uses a different combination of collector panels and inverters, with five different types of panels and four different types of inverter. Measurements taken include input DC current and voltage for 5 inverters, AC current and voltage output from each inverter to a combiner panel, wind speed, global and incidental solar radiation, ambient temperature, and panel temperature.

The University of Oregon Solar Radiation Monitoring Lab has been monitoring photovoltaic systems through a grant from the Energy Trust of Oregon. Previous studies have looked at the effects of shading and individual system performance. The AEC project provides an opportunity to directly compare the performance of different systems

2. PROJECT GOALS

2.1 System Performance: One of the goals of the test facility is to evaluate inverter and panel performance under different environmental conditions. Since panels are subject to comparable daylight conditions direct comparisons between systems can be made.

2.2 System Loading: As can be noted from the system configuration description, Total panel DC capacity exceeds inverter rating for systems 6, 7 and 8. How these inverters perform in peak power production periods will be evaluated.

2.3 Inverter heating: Inverter temperature is measured against AC power output and the effects of temperature on inverter efficiency will be evaluated.

2.4 Comparison of monitoring methods: Fat Spaniel Technologies offers a very cost effective PV monitoring option. Accuracy of Fat Spaniel's transducers will be measured by comparing metered results with the Solar Radiation Lab's monitoring equipment. The accuracy of RS 485 output data from the inverters, when available, will also be measured.

2.5 Test the ability of system monitoring to detect system problems: System monitoring should be an effective tool in identifying system problems and monitoring system performance.

3. SYSTEM DESCRIPTIONS

The AEC PV test facility provides a method for comparing performance of different PV arrays and inverters. In addition to power production, solar radiation, wind speed, outdoor temperature and PV module temperature readings are recorded. The following table describes the monitored systems:

TABLE 1: SUMMARY OF MONITORED SYSTEMS

System	DC Rating	Inverter	Panels
1	2338 Watts	SMA 2500U/208 2500 Watt	Sharp #ND-167UI 1 string of 14 panels
2	2338 Watts	SMA 2500U/208 2500 watt	Kyocera #KC167G 1 string of 14 panels
3	2505 Watts	Fronius 2500-LV 2500 Watt	Sanyo #HIP-G751 BA2 – 3 strings of 5 panels
4	3465 Watts	Sharp Sunvista 3500 – 3500Watt	Sharp #NE-165UI 3 strings of 7 panels
5	3465 Watts	Sharp Sunvista 3500 3500 Watt	Isofoton #1-165 (1) string of 10 & (1) string of 11 panels
6	3600 Watts	PV Powered 2800/208 2800 Watt	Isofoton #1-150S - 24V 3 strings of 8 panels
7	3600 Watts	PV Powered 2800/208 Watt	BP # BP 3150 3 strings of 8 panels
8	3675 Watts	PV Powered 2800/208 2800 Watt	Sharp #NT-175UI 3 strings of 7 panels

The system modularity allows for easy modifications to made to the system, such as pairing of inverters with PV arrays and adding modules to test inverter loading. In the coming year changes will be made to the current configuration in order to analyze the performance differences between systems.

3.1 Monitoring Equipment

The eight systems were monitored using software developed by Fat Spaniel Technologies. Additional equipment installed by the University of Oregon Solar Radiation Monitoring Lab augments the data collected by Fat Spaniel equipment. The Fat Spaniel monitoring system uses transducers for AC power production data collection. In addition, data is collected from the 485 output port from the SMA inverters.

Specific equipment used L is as follows:

Fat Spaniel Monitoring:
Current transformers: Ion CT-5B model 1052 ARW
Meters: Ion 6200
Thermocouple: Superlogics 61xjbex36a
Pyranometer: Apogee Instruments
Gateway: N-Port programmable communication gateway

University of Oregon Solar Radiation Monitoring Lab:
DC Voltage transducers: OSI VT7 DC
AC Watt transducers: OSI PC5
Current transducers: OSI CTL DC Hall effect current sensor with Empro DC current shunt
Li-cor LI-200 horizontal and tilted pyranometers
Minco RTD PV temperature sensor
Campbell Scientific 107 air temperature sensor
RM Young 03101 anemometer
Campbell Scientific data logger system

4. SAMPLE RESULTS

4.1 System Performance:

A performance comparison for the 8 systems tested over the course of one year is summarized in Table 2.

TABLE 2: POWER PRODUCTION COMPARISION

Data Summary - January 1,2005 through December 31, 2005

Sys #	DC Watt Rating	kwh generated	Efficiency	% Deviation Average	% Deviation w/o 4 & 5
1	2338	2517.06	0.1229	2.5860	-0.2451
2	2338	2599.41	0.1269	5.9423	3.0186
3	2505	2689.79	0.1226	2.3175	-0.5062
4	3465	3517.28	0.1159	-3.2741	
5	3465	2783.51	0.1030	-14.0156	
6	3600	3746.19	0.1188	-0.8423	-3.5788
7	3600	3616.41	0.1230	2.6755	-0.1581
8	3675	4032.24	0.1253	4.5510	1.6656

Average Efficiency Rating: 0.1198

Average without Systems 4 & 5: 0.1232

Efficiency, or capacity factor, is defined as AC power output in kilowatt hours / DC KW power rating x hours of operation. Data are from Fat Spaniel's monitoring system.

The results in Table 1 show very similar performance between systems, with all systems within 6% of the average except system #4. Systems 4 &5 show the poorest performance over the year. These two systems use 240 volt inverters and the power is converted to 208 volts using dry type transformers. Monitoring data are taken at the secondary of these transformers. Since inclusion of systems 4 and 5 skews the data due to transformer losses, deviation from average was calculated with systems 4 & 5 included and recalculated with these systems excluded. With systems #3 and #4 removed, the performance of all other systems is within ±4% of the average. This is remarkable considering the shading and other factors affecting performance.

It is suspected that the relatively poor performance of system #5 is also related to the PV panel performance. In the coming year the PV panels will be rewired to different inverters in order to determine how much of the performance difference is related to the PV panels and how much is related to the inverter.

Performance of the eight systems on a typical summer day is shown in Fig. 1. AC power over time is normalized by dividing by the peak DC system rating and plotted against incident solar radiation.

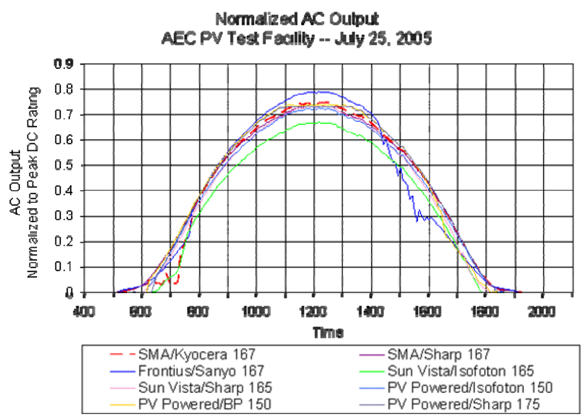

Fig. 1: Comparative System Performance

The compromised performance of the Sharp Sunvista systems (Systems 4 and 5) due to transformer losses can be clearly seen in this plot. It should also be noted that performance of systems 2 and 3 are affected by shading, resulting in a decrease in performance. The symmetry of the surve was somewhat surprising. We had expected morning production to be higher than afternoon production due to lower morning temperatures. Comparing readings at 10:20 and 14:20 shows a 7% drop in performance in the afternoon at 8% higher levels of irradiance. We do not have a good explanation for this result, and will study it more in the coming year.

4.2 System Loading

Fig. 2 is a plot of three measurements of AC Power Output by PV Powered inverter number 8 on a sunny day in September.

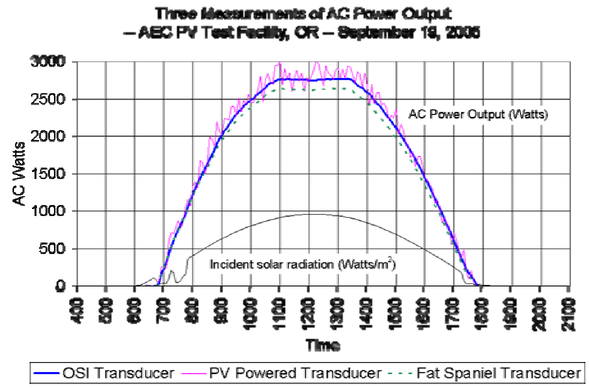

Fig. 2: System #8 plotted against Incident Solar Radiation

Note that the power production curve flattens at peak power production of 2800 watts. The DC power rating on this array is 3675 watts. We conclude that considerable power is lost at high levels of solar radiation due to the mismatch of DC power rating and AC inverter rating. At peak power production the inverter electronics regulate voltage and current in order to dissipate excess energy. This is illustrated in Figs 4 & 5.

The jagged line in Fig. 2 is the output of the 1 minute data from the PV Powered transducer averaged over 5 minutes. There is considerable variation (noise) in the output of the PV Powered transducers. The PV Powered 2800 inverter produces a large magnetic field (0.5 Gauss at frequencies above 120 kilohertz near the inverter) and this affects measurements made with Hall effect sensors (This measures DC current). The Ohio Semitronic Instruments (OSI) watt transducer is a current transformer. Noise problems were only noted with the PV Powered inverters.

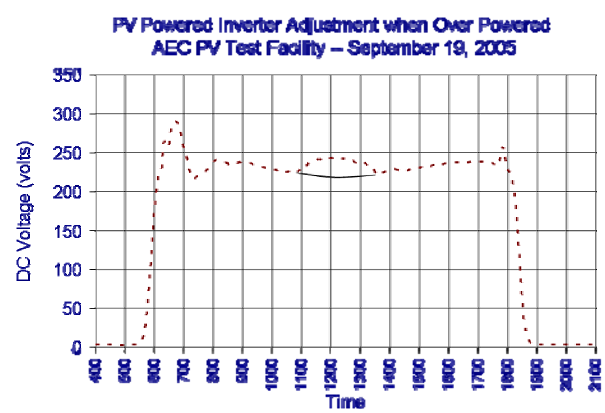

Fig. 3: Voltage changes at peak power production

Figs. 3 and 4 show incident solar radiation for the same inverter on the same day plotted against inverter voltage and current.

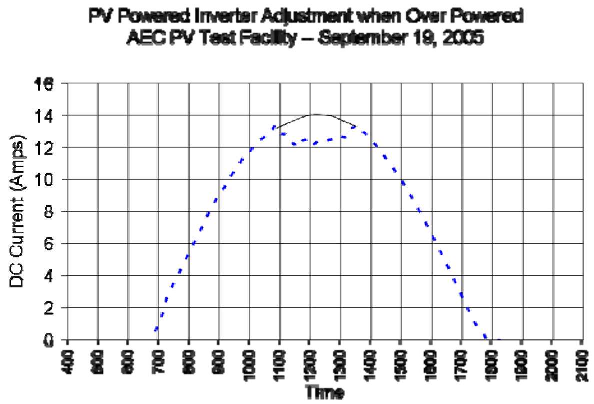

Fig.4: Current changes at peak power production

It appears that when the inverter reaches its nameplate rating that it moves away from peak AC power production voltage. This voltage change reduces AC current which protects the inverter. As a result, power is lost during peak solar radiation periods when systems are loaded beyond their nameplate rating. The PV Powered inverters, systems 6, 7, and 8 are loaded 30-40% above its nameplate rating. In the coming year the load will be reduced on these inverters. We anticipate some system efficiency improvement with a better match between panel DC power rating and inverter rating.

4.3 Affects of temperature on performance

Fig. 5 is a scatter plot of power output versus temperature throughout the month of February. The data is fairly consistent and is linear indicating there is no fall off in efficiency with inverter heating.

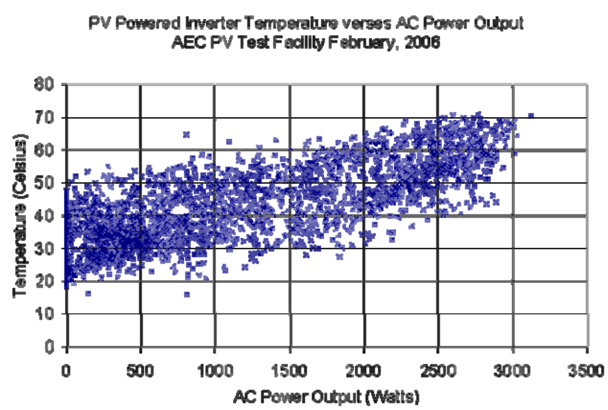

Fig. 5: AC power output versus temperature

The inverter remperature increases about 1 degree C for each 100 watts of AC output. We have concluded that moderate temperature is not negatively affecting performance for this installation. In the coming year we plan to locate one of the inverters outdoors where it will be subject to additional heating on summer days.

4.4 Comparison of monitoring methods

Fig. 6 is a plot of the ratio of the AC output for the transducers used by Fat Spaniel and OSI transducers. The reason for the slope is that the time in the Fat Spaniel is off by about 8 minutes. The two sets of transducers are consistent in their reading, although Fat Spaniels' transducer readings are consistently about 6% below the readings of the OSI watt transducers. The readings of the SMA output a few prevent higher than the reading from the OSI watt transducers . Differences in readings can be attributed to grounding to shield from magnetic flux from the PV Powered inverters and calibration.

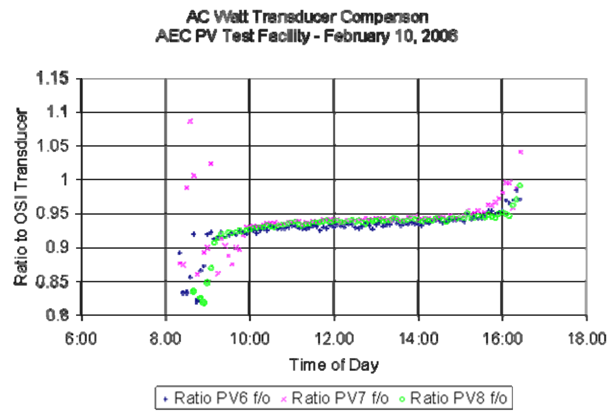

Fig. 6: Comparison of Fat Spaniel and OSI Transducers

Fig. 7 is a comparison of the RS485 output from the SMA inverters, Fat Spaniel transducer output and the OSI transducers used by the Solar Radiation Lab's monitoring equipment for systems 1 and 2.

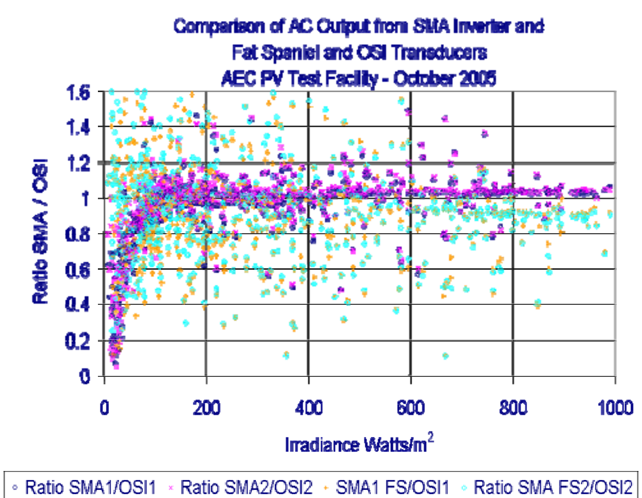

Fig. 7 Comparison of RS 485 and OSI transducer data

Note that the SMA inverter records are 3-4% higher output than the OSI transducers used by the Solar Radiation Lab, except at levels of solar radiation below 100 W/m^2. This is a characteristic shown by both SMA inverters. The data were taken over the last 5 days of October and there were not any completely sunny days in this time period. Note that the data from the Fat Spaniel transducers is about 10% below the OSI values for high periods of irradiance and very close to the OSI values during low periods of irradiance. Average difference in readings was about 6%.

Fig. 8 plots the ratio of the PV Powered inverter output to the OSI transducers over time.

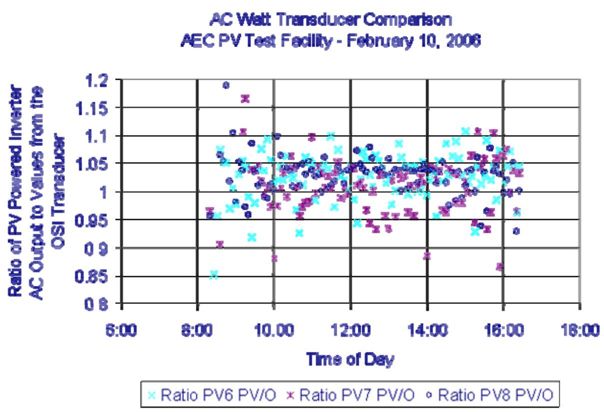

Fig. 8 Transducer output ratio over time

There is an excessive amount of noise in the PV Powered data, but they agree fairly well with the measurements of the OSI transducers. The ratio stays fairly consistent over the course of the day and the scatter is typically less than 5%. The PV Powered values are one minute samples averaged over 5 minutes. It is postulated that differences in readings can be attributed to calibration of the transducers and the need to ground the shield wire in order to minimize the effect of magnetic flux from the PV Powered inverters.

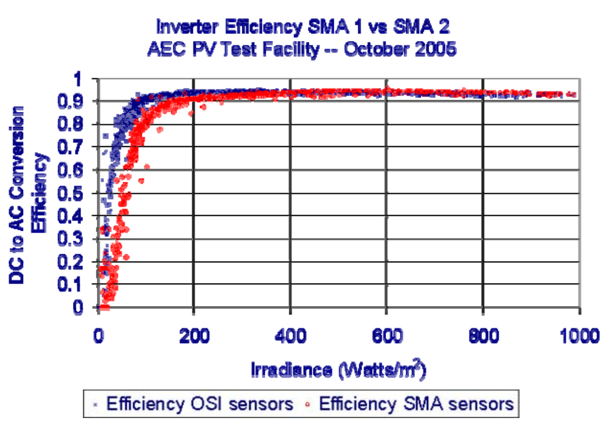

Fig. 9: Comparison of Efficiencies, Systems 1 & 2

Fig. 9 shows a comparison of efficiency readings by Fat Spaniel's and UOSML's monitoring equipment for the two SMA inverters.

The efficiency of system #1 is fairly linear across irradiance levels. System #2 shows lower efficiency at lower irradiance levels. It was determined that this was due to differences in the monitoring equipment .

4.5 Ability of system monitoring to detect system problems

During the course of monitoring it was discovered that systems 6 and 8 would drop out under peak power conditions. After a five minute pause, the system would come back up. The inverter manufacturer determined that this is characteristic of the system utility voltage or phase out of range. A firmware change by the manufacturer was able to correct this problem. Without monitoring, the problem could have continued unnoticed.

Fig. 10 shows system #6 dropping off line during periods of high solar irradiance.

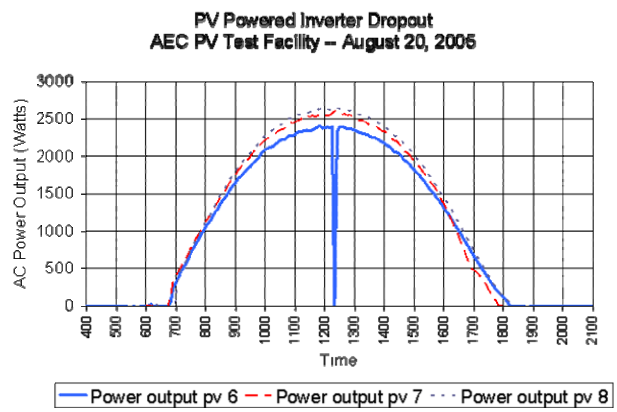

Fig. 10 Dropout of inverter #6

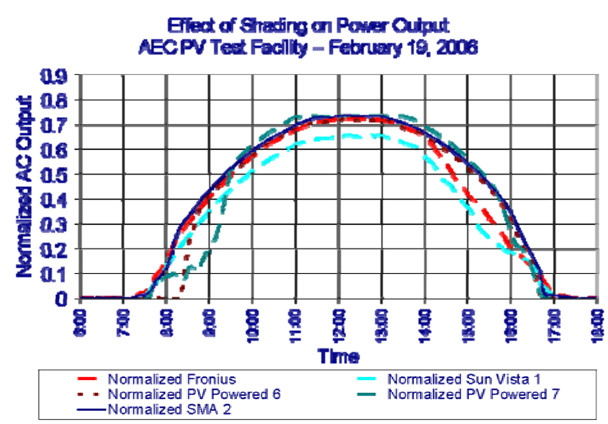

Fig. 11 Shading effects on systems 2, 3, 4, 6 and 7

Fig. 11 shows the effects of shading on systems 2, 3, 4, 6 and 7. Note that potential shading problems can be identified for specific time periods. This potentially allows the Owner to address power losses due to shading by identifying the source of shading.

Even though system #3 has a noticeable decrease in production in late afternoon, the annual power production of this system was only slightly compromised due to production level at the peak of the day. At this time we are not sure of the cause for the decrease in power production in the afternoon.

5. CONCLUSIONS

5.1 System Performance.

Small efficiency differences between manufacturer's equipment were noted. Ongoing studies will attempt to determine specific reasons for these performance differences.

5.2 Effect of Inverter Loading

The DC watt load for inverters 6, 7, and 8 exceeded the inverter watt rating by 30 – 35%. The effect of this loading condition was a flattening of the AC power production curve as inverter nameplate rating was reached. This was characterized by an increase in voltage and decrease in current as the inverter moved away from peak power voltage to protect the equipment. The compensation at peak power production appeared to have a negligible effect on performance. The overall annual performance of these three systems was comparable to the other systems studied. In the coming year we will be reducing the load on these three inverters to evaluate the effects of overloading system inverters, especially to see if system overloading affects overall efficiency.

5.3 Effect of Inverter Temperature

System performance showed little efficiency decrease with rise in inverter temperature. It should be noted that inverters are located indoors and measured temperatures were well within inverter manufacturer's recommendations. It was observed that the inverter temperature rises approximately 1 degree Celsius per 100 watts of AC output. Temperature rise could become an issue for installations where the inverter is exposed to sunlight.

5.4 Comparison of monitoring methods.

Photovoltaic system monitoring is highly recommended for all photovoltaic systems in order to maximize system performance by identifying systemic problems and enabling notifications of system shutdowns. Fat Spaniel Technologies offers a very cost effective PV monitoring option. In general we found that the data from Fat Spaniel's transducers were about 6% lower than the data from the OSI transducers used by the Solar Radiation Lab. This difference was consistent across systems. We found the RS485 output readings from the SMA inverters to be about 3-4 % higher than the values read from the OSI transducers.

The conclusions we have drawn from these monitoring comparisons is that any of the monitoring methods can be a useful tool in evaluating system performance. However, calibrating the measurement instruments is essential for detailed analysis of power production. In addition, one must be careful to make sure the transducers are properly grounded and interference electrical and magnetic emissions are minimized.

5.5 Ability of system monitoring to detect system problems.

The monitoring equipment proved to be quite an effective tool in identifying system performance problems..

6. FURTHER STUDIES

In the coming year the following system modifications will be made to further analyze system performance:

1. The PV arrays feeding inverters 2 and 3 will be reversed to determine whether performance differences are related to the inverter or to the PV array.
2. As noted earlier, inverters 6, 7 and 8 are loaded to 30 – 35% over inverter nameplate rating. One of the strings will be disconnected from inverter #7 and compared to the power produced by inverters #6 and #8.
3. The PV arrays feeding inverters 6 and 8 will be reversed to determine whether performance differences are related to the inverter or to the PV array.
4. Inverters 4 and 5 will be replaced with two different manufacturer's inverters, eliminating the losses associated with the step down transformers.

7. Acknowledgements

We would like to thank the Energy Trust of Oregon, the Eugene Water and Electric Board and the Bonneville Power Administration for project funding and support of the UO SRML solar and PV monitoring efforts.

8. REFERENCES

1. Frank Vignola: Using Sun Path Charts to Estimate the Effect of Shading on PV Arrays, Proc. Solar 2004, American Solar Energy Society Conference, Portland, OR. 2004.