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QUARTERLY TECHNICAL REPORT

Second Quarter 1994

By
PVUSA Project Staff

Pacific Gas & Electric Company
Research and Development Department
San Ramon, CA 94583

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**PHASE II -- PHOTOVOLTAICS FOR
UTILITY SCALE APPLICATIONS
(PVUSA)**

**QUARTERLY TECHNICAL REPORT
Second Quarter 1994**

PVUSA Project Staff

**Pacific Gas & Electric Company
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I. SUMMARY

Seventy-five people attended PVUSA's "Grid-Support PV: Application and Assessment" workshop in San Francisco on June 9-10. Results from the Kerman project's distributed benefits evaluation were presented, along with results of four Sandia-sponsored utility case studies. Presentations on SMUD's and UPVG's PV programs were given, and several speakers addressed broader issues, such as the role of distributed generation in the changing utility environment, utility restructuring, and PV markets and applications.

SMUD's 200-kW UPG system at their Hedge substation site in Sacramento, California was brought on line in early April and christened at a dedication ceremony on April 18. This system uses SSI modules mounted on twenty rows of UPG-designed one-axis tracking structures, with power fed to a single Omnion PCU.

In May, SSI notified PVUSA that it would cease additional work on its US-1 system at Davis. Rather than continue development work on both of the system's Blue Point PCUs, SSI requested to close out its contract with just one of the system's two PCUs in operation. One unit, inverter "A", continued to fail after over two years of troubleshooting and repairs. The other unit, inverter "B", has operated reasonably well, although it too has frequently tripped off line. The half system was rated at 67 kW, 23% less than expected based on one half of the contract target 174 kW. Subsequent I-V curves suggest much of the shortfall may be traced to a 15% shortfall in the dc array field's maximum power.

The EMT and US systems at six PVUSA sites generated nearly 750,000 kWh this quarter, the same energy used by about 500 homes over the same period. For the first half of 1994, the performance index, or ratio of actual to expected generation, has exceeded 90% for six of the twelve completed systems for which data are available. Five of the remaining six systems have generated between 80% and 90% of their expected output. The remaining system, IPC's 200-kW US-1 system at Davis, has been limited by continuing problems with its Omnion PCU; its performance index over the first half of the year was just 29%.

A table of key second quarter 1994 and annual 1993 results follows. Performance data for SMUD's 200-kW UPG system in Sacramento and the Davis site's 200-kW SSI system are not included. The data acquisition system for the SMUD system is not yet complete, and the Davis SSI system had not yet begun full operation pending a contract settlement, but data for each system is expected to be included in the next report.

Emerging Module Technologies 1993 avg. = []	Efficiency %	Capacity Factor %	System Availability ¹ %
SSI	10.0 [10.2] dc	23 [19]	80 [80]
Sovonics Davis	2.7 [2.6] dc	22 [16]	79 [72]
Sovonics Maui	3.3 [3.3] dc	19 [21]	78 [85]
UPG	2.8 [2.9] dc	25 [19]	90 [85]
Solarex	7.8 [7.4] dc	23 [18]	76 [76]
ENTECH	11.0 [11.1] dc	28 [15]	68 [41]
NREL Maspeth	4.2 [- -] dc	20 [-]	81 [-]
Utility Scale Systems 1993 avg. = []			
APS	3.2 [3.2] ac	21 [13]	82 [64]
SSI Kerman	8.9 [8.8] ac	34 [23]	92 [92]
IPC Davis	8.1 [8.1] ac	11 [13]	29 [40]
IPC Austin	8.1 [8.1] ac	21 [18]	75 [73]
IPC NYSERDA	8.4 [- -] ac	21 [-]	77 [-]

¹ Defined here as the percentage of daytime hours when the PV system supplies net power to the utility.

II. PROJECT MANAGEMENT

1. Schedule Analysis

PVUSA's Construction & Safety workshop has been scheduled for September 14-15, 1994.

AstroPower is maintaining its schedule for completing the 20-kW Davis EMT-2 array. Qualification tests were completed in late June. Work is proceeding on schedule to deliver 15 sample modules in August. Completion date is expected somewhere between the "early" forecast date of October 1994 and the "late" December 1994 date. PVUSA has the option to terminate the contract in the event the schedule cannot be maintained by AstroPower.

In May, SSI requested to close out the contract for their US-1 system at Davis even though only one of the system's two PCUs was functioning. PVUSA agreed (in July) to accept the system and rate the functional half. Using data from late May until early June, the system was rated at 67 kW, 23% short of the expected rating for half of the 174 kW contract capacity. The other half of the array may be used to supply dc power for a future PCU testbed, and the inoperative PCU will most likely be used for spare parts for the other PCU.

	Original Estimated Completion Date	Current Forecast Completion Date
EMT:		
AstroPower	May 1990	4th qtr. 1994
US:		
SSI Davis	October 1990	July 1994

2. Cost Analysis and Funding Activities

PG&E and DOE Albuquerque staff met in April to discuss closure of the first 5-year cooperative agreement and to come to agreement on various terms and scope for the 1994 proposal. DOE has been backlogged in contracts and requested a 2-month hiatus in processing our proposal. Processing is expected to resume in August.

Expenditures for the first six months of 1994 were \$810,000 of the budgeted \$2,900,000 for 1994. Expenses are lower than originally planned due to delay/rescheduling of payments to Siemens (US-1) and AstroPower (EMT-2). The 1994 budget will reduce (possibly significantly) pending negotiations with SSI on closure of the US-1 contract.

3. Principal Activities

The principal activities which took place this quarter are detailed by subcategory.

EMT

At the ASES conference in June in San Jose, California, Tim Townsend presented PVUSA's paper detailing five years of EMT performance. The paper, titled "Emerging Module Technologies at PVUSA: A Five-Year Performance Assessment," will be expanded into a detailed report to be issued this fall.

AstroPower indicated in late June that they had successfully completed the qualification testing phase of their EMT-2 module development. Although cell efficiencies are still about 10% below target and they are still experimenting with adhesives for the frame/module bond, AstroPower is proceeding with cell production and expects to maintain their overall schedule.

The overall operation of the EMT arrays this quarter was good, although the ENTECH array continued to experience problems with its tracker controller, and the Solarex array's PCU failed, resulting in several days of downtime. The total EMT maintenance logged this quarter was about 11 hours.

The Solarex array's DECC/Helionetics PCU began to trip off line with increasing regularity in May. At first, the unit responded to manual resets, but eventually, it began to trip immediately. The problem was traced to a failed control board, and a replacement board was installed and adjusted in late June.

The ENTECH array's tracker controller was reset on five occasions and needed to be replaced once, in April. ENTECH was scheduled to install a new dc-based controller system in June, but the retrofit has been delayed to August because of delays experienced by ENTECH in obtaining components.

US-1

The APS system improved its performance index, or ratio of actual to expected output, from 79% over the first three months of 1994, to 84% over the second quarter. The system still required about 10 hours of failure-related maintenance by APS and PVUSA personnel, mostly to troubleshoot and repair PCU problems. The array continues to operate at a slightly reduced power output due to at least 23 cracked modules (of 9600) and 6 (of 960) non-contributing 10-module panels. Early in April, APS replaced the last of several underrated dc contactor coils, completing a retrofit that began earlier this spring. Ongoing problems include occasional fuses blowing as a result of grid disturbances and inaccurate voltage signals and an inability to adjust some of them to peak power settings. APS planned to replace the cracked modules and repair the non-contributing panels in July, but as of early August, this work had not yet taken place.

The IPC system was off line for most of the quarter, generating just 24% of its expected output. The system experienced failures on both its tracker controller and its PCU. Over 18 hours of maintenance time was spent troubleshooting the system. Repairs to the tracker controller were relatively simple (two I/O modules needed to be replaced), but the PCU problems have yet to be resolved. Over \$4,000 in new components are needed after a major incident in mid-May which damaged two bridges. The root cause of the unit's continuing trips has not been determined. PVUSA and IPC/Omnion are presently discussing a repair plan, with troubleshooting planned for August.

In May, SSI decided to cancel its plans to fully complete its US-1 system at Davis. Rather than continue development work on both of the system's Blue Point PCUs, SSI requested to close out its contract with just one of the system's two PCUs in operation. One unit, inverter "A", continued to fail after over two years of troubleshooting and repairs. The other unit, inverter "B", has operated reasonably well, although it too has frequently tripped off line. PVUSA plans to use the idle unit "A" for spare parts and use the idle half of the array field to power new inverters as part of a new test program. The half system was rated at 67 kW under PTC based on performance data collected in May and June. Compared to the expected contract rating of one-half of 174 kW, this represents a 23% shortfall. Reasons for the shortfall are being investigated. Subsequent I-V curves taken in July suggest that 15% of the shortfall may be in the dc array field.

US-2 Kerman

The Kerman US-2 system experienced several interruptions due to system component and grid disturbances, but its overall performance was good: the system demonstrated a daytime availability of 92% and generated about 92% of the maximum energy expected under the given weather conditions. The total O&M time logged for the quarter included 12 hours for planned activities and 27 hours for failure-related activities, for an average O&M

cost of about 0.5 cents/kWh.

In addition to scheduled maintenance activities in April and May, failure-related troubleshooting and repair work was conducted by PVUSA, PG&E Fresno staff, Omnion, and a few subcontractors. The principal activities included air-conditioning service in April and May to repair a failed compressor on PCU #2's unit and in June to repair a refrigerant leak on PCU #1's unit. PG&E SCADA technicians repaired a failed fiber-optic communications cable connector in April that had shut down PCU #2 for one week. Two more passive tracker actuators were replaced, bringing the total number of failed actuators to 10 (of 77) after one year of operation. In addition, SSI replaced 40 passive tracker evaporator tube covers, which were believed to be damaged by hail earlier this spring. The system also required remote manual resets by PG&E Fresno staff after several PCU trips of unknown cause.

In June, the plant tripped on a hot day (101 °F) due to a line undervoltage condition. The system could not be restarted for about six hours until the line voltage rose above a preset minimum threshold, but provided about 150 V per phase of voltage support (of 7,200 V) once it was restarted.

Special tests were conducted in May for analyzing voltage support and in June for analyzing line loading. A meeting was held in May with PG&E Fresno staff to discuss transitional O&M responsibilities as the plant moves closer to full utility operation, with less research presence.

Safety

The PVUSA Safety Committee met and discussed office ergonomics.

4. Technology Transfer Activities

Publications, Conferences, and Meetings

April:

The PVUSA Technical Review Committee met to review the PVUSA Construction and Safety Report. Work began on revising the report based on TRC feedback.

The 1993 PVUSA Progress Report was received from the printer and distributed.

PVUSA contributed an article for UPVG's newsletter, VISION.

May:

Six abstracts were approved by DOE, EPRI, CEC, and PG&E and submitted to the First World Conference on PV Energy Conversion.

June:

A PVUSA Steering Committee meeting was held in San Francisco. Issues discussed included SSI US-1, PVUSA business plan development, and membership options.

PVUSA sponsored the Grid-Support PV: Application and Assessment Workshop, held at PG&E's Energy Center in San Francisco. The workshop reviewed the Kerman validation results to date, presented results of the four

SANDIA-sponsored studies, and compared results in a panel discussion. Other topics discussed included the role of distributed generation in today's utility environment, restructuring of the utilities, and markets and applications.

PVUSA participated in the ASES Solar '94 Conference held in San Jose. Kerman lessons learned and benefits validation results to date and two PVUSA papers, "Emerging PV Module Technologies at PVUSA: A Five-Year Performance Assessment" and "The Value of Grid-Support PV in Providing Distribution System Voltage Support," were presented. A PG&E-sponsored booth featured PVUSA's exhibit, selected publications, and flyers announcing PVUSA's Construction and Safety workshop.

As part of the DOE's PV Program Peer Review, PVUSA staff prepared and submitted program and personnel background information to the DOE.

PVUAS participated in the NREL Standards and Codes Forum June 27-30 in Golden, CO. In addition to reviewing and providing input on a number of documents, PVUSA field acceptance test procedures are being used as the basis for a new IEEE Standard P1373, "Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems."

Site Tours

During the second quarter of 1994, PVUSA hosted 29 tours of the Davis site for a total of 161 visitors, including special weekend tours in conjunction with a Davis Earth Day event in April and with the ASES conference in June.

III. TECHNICAL ANALYSIS - DAVIS SITE

1. System Performance

Table III.1 lists recent energy, efficiency, capacity factor, and insolation data for each system. Dc efficiencies are shown for the EMT arrays and ac efficiencies are shown for the US systems. The insolation totals differ, even for arrays of the same orientation. They differ primarily because this quantity is integrated only when the PCU is on, and the hours of PCU operation vary between arrays. In addition to the normal variation between instruments (typically $\pm 3\%$), there are also small differences in the field of view from each array.

Overall, the PV systems operated under normal seasonal conditions, with the site receiving about 2% less global 30° tilt insolation than the 2nd quarter average over the past five years. The average ambient temperature was 0.5 °C below the five-year average, and the average wind speed was 0.3 m/s less than the five-year average of 3.4 m/s. The quarterly rainfall of 1.8" was about 7% above the five-year average, but this was still 6% less than the long-term average, and did not occur frequently enough to keep the arrays from becoming lightly but visibly soiled by the end of June.

The Performance Index (P.I.), or ratio of actual to expected generation, was introduced in the previous report. After accounting for the present condition of a system (that is, if it has degraded) and for scheduled and externally caused outage time, additional adjustments are made to account for differences in module temperature and insolation between PTC and actual conditions. The resultant P.I. provides an estimate of generation lost due to factors such as failures and soiling. The quarterly Performance Indices for the Davis systems are shown in Table III.2.

These results indicate that for the SSI, Sovonics, and UPG arrays, the "lost" generation was 10% or less for the past quarter. For the Solarex, ENTECH, and APS arrays, the "lost" generation was between 12% and 15%. The IPC system was down for much of the quarter and consequently "lost" about 75% of its potential generation.

Figure III.1 tracks the monthly energy supplied by the Davis site EMT systems over the past 15 months. Figure III.2 shows the same information for the US-1 systems, including startup and testing energy delivered prior to system completion. The right scales refer to insolation measured at the site weather station (integrated over all hours). On both plots, the 30° tilt insolation is shown as a reference trend for the fixed tilt systems. On Figure III.1, the 1989-93 monthly average 30° tilt insolation is also included, and on Figure III.2, the horizontal N-S 1-axis insolation is included as a reference trend for the IPC tracking system.

The monthly energy production patterns generally follow the insolation trends, except that the array energy production also reflects outages, limited operation during installation and startup, and seasonal efficiency variations. Of particular note is the June output for the ENTECH array. Its 4,218 kWh, corresponding to a monthly capacity factor of nearly 38%, was the highest monthly total for this system in over three years of operation. It appears extraordinary relative to the insolation trend, but this array operates on direct normal insolation, and this June, the direct normal insolation jumped over 60% compared to April and May.

Table III.1
2nd Quarter 1994 Performance Summary

Characteristics	SSI	Sovonics	UPG	Solarex	ENTECH	APS	IPC
Orientation (fixed flat plate, tracking)	30° ffp	30° ffp	30° ffp	30° ffp	2-ax trkr.	30° ffp	1-ax trkr.
Initial rating	18.7 kWdc	17.3 kWdc	15.7 kWdc	15.7 kWdc	16.5 kWdc	479 kWac	196 kWac
Installation date	1/89	6/89	12/89	10/90	3/91	9/92	6/93
Module area, m ²	169	497	477	182	172	11520	2443

System	Quantity	1992	1993	Cumul. 94	Apr 94	May 94	Jun 94
SSI EMT-1	AC kWh	29261	29891	15688	2904	3018	3207
	DC eff. %	10.1	10.2	10.3	10.3	10.1	9.7
	AC cap.fac. %	18.5	18.9	20.0	22.3	22.5	24.7
	Insol. kWh/m ²	1978	1962	1008	187	199	218
Sovonics EMT-1	AC kWh	12181	22758	11927	2354	2540	2802
	DC eff. %	2.8	2.6	2.6	2.7	2.7	2.8
	AC cap.fac. %	8.7	16.3	17.3	20.6	21.5	24.5
	Insol. kWh/m ²	1000	1970	1036	196	208	224
UPG EMT-1	AC kWh	25407	25479	13317	2512	2731	2897
	DC eff. %	3.0	2.9	2.8	2.8	2.9	2.8
	AC cap.fac. %	19.2	19.3	20.3	23.1	24.3	26.7
	Insol. kWh/m ²	1917	1963	1051	199	212	229
Solarex EMT-1	AC kWh	22767	23572	13144	2595	2626	2359
	DC eff. %	7.3	7.4	8.0	8.0	7.9	7.6
	AC cap.fac. %	17.2	17.8	20.0	23.9	23.4	21.7
	Insol. kWh/m ²	1936	1968	1012	197	204	188
ENTECH EMT-1 (91 data based on 9 mos.)	AC kWh	21117	20032	16069	2375	3057	4218
	DC eff. %	10.7	11.1	11.3	11.4	11.5	10.4
	AC cap.fac. %	15.4	14.7	23.7	21.1	26.3	37.6
	Insol. kWh/m ²	1228	1123	848	128	166	250
APS US-1 (92 data based on 3½ mos.)	AC kWh	214508	530047	353920	73854	64534	78988
	AC eff. %	3.8	3.2	3.2	3.4	3.0	3.2
	AC cap.fac. %	15.3	12.6	17.0	21.4	18.1	22.9
	Insol. kWh/m ²	494	1396	946	186	184	217
IPC US-1 (93 data based on June start)	AC kWh	--	188541	81739	21664	24311	0
	AC eff. %	--	8.1	8.3	8.1	8.0	0
	AC cap.fac. %	--	12.6	9.6	15.4	16.7	0
	Insol. kWh/m ²	--	9741	403	110	124	0

Table III.2
1994 Performance Indices

System	2nd quarter	Cumulative 1994
SSI	90%	91%
Sovonics	93%	85%
Solarex	88%	90%
UPG	98%	95%
ENTECH	87%	91%
APS	85%	82%
IPC	25%	29%

PVUSA DAVIS EMT SYSTEMS RECENT OUTPUT and INSOLATION

Insolation: global, 30 degree tilt, south-facing
 Average Insolation based on 1989-1993
 ENTECH is a 2-axis tracking array that converts direct normal insolation only

Figure III.1

PVUSA UTILITY SCALE SYSTEMS RECENT OUTPUT and INSOLATION

Orientations: APS = fixed 30 deg.
 IPC, SSI = 1-axis

Figure III.2

Figure III.3 shows each Davis system's monthly average efficiency. Dc efficiencies are reported for the five EMT arrays, and ac efficiencies are reported for two US systems. Except for the ENTECH array, the efficiencies are calculated as the ratio of monthly energy produced to monthly plane-of-array insolation during hours when the PCU was operating. The ENTECH array, which uses a 22X concentrating lens and two-axis tracking structure, shades portions of itself and its pyrheliometer during the early and late hours of the day. Therefore, its efficiency calculations are based on the hours between 9 am and 3 pm PST, when shading does not occur at any time of the year.

PVUSA DAVIS SITE EFFICIENCIES

EMT: dc efflc.; US: ac efflc.

Figure III.3

Figure III.4 shows system availabilities for the five EMTs and two US systems at Davis. The availability is defined to be the percentage of daytime hours during which the system supplies net power to the utility. During the hours near sunrise and sunset, the irradiance and PCU efficiency are often too low to produce net power output. However, the amount of unused potential energy during the sunrise and sunset hours is small; typically, less than 2% of the total daily insolation. The amount of time during which array power is not high enough to overcome the PCU's internal loads and/or reach its preset startup threshold varies among PCUs. Typically, this is roughly 60 minutes per day.

Several systems continued to operate at very good availabilities of 80% or greater. The ENTECH array's quarterly availability improved somewhat compared to the previous year, even though it was down for several days in April due to tracker controller failures. The IPC system's PCU problems limited its overall availability to 29% for the quarter.

PVUSA DAVIS SITE DAYTIME SYSTEM AVAILABILITIES

Availability is defined as the % of
daytime hours w/power supplied to grid
[IPC 2nd qtr. '93 based on 6/93 only]

Figure III.4

2. Solar/Weather Data

Table III.4 lists several 1992 and 1993 annual, and second quarter 1994 solar radiation, temperature, and wind speed statistics. Overall, the quarterly global horizontal insolation was 3% below the long-term average. The average ambient temperature was 0.5 °C below the five-year average, but this was still about 0.9 °C above the area's long-term average. The average wind speed was 0.3 m/s less than the five-year average of 3.4 m/s (long-term average wind speed data are not available for the site). The quarterly rainfall of 1.8" was about 7% above the five-year average, but this was still 6% less than the long-term average. Figure III.5 shows the monthly insolation over the past 15 months for five orientations: global horizontal, global 30° tilt, global normal, direct normal, and global north-south single axis.

Table III.4
2nd Quarter 1994 Solar/Weather Summary

Insolation, kWh/m ² ; Peak Irradiance, W/m ²	1992	1993	Cumul. 94	Apr 94	May 94	Jun 94
LT-Avg. global horizontal insolation	1838	1838	944	184	229	245
Global horizontal insolation	1827	1801	961	182	215	256
Peak 10-min. avg. irradiance	1142	1198	1156	1095	1146	1156
Global 30° tilt insolation	2038	2036	1046	194	206	230
Peak 10-min. avg. irradiance	1192	1232	1297	1163	1177	1152
Global normal insolation	2819	2900	1507	274	306	380
Peak 10-min. avg. irradiance	1214	1268	1321	1199	1246	1203
Horizontal 1-axis tracking insolation	2498	2593	1383	263	300	377
Peak 10-min. avg. irradiance	1124	1230	1233	1129	1233	1175
Direct normal insolation	1839	2064	1052	187	185	304
Peak 10-min. avg. irradiance	946	1022	983	981	943	982
Minimum T _{ambient} , °C	-2.9	-4.8	-2.5	2.9	4.6	7.2
LT-Avg. T _{ambient} , °C	15	15	13	14	17	21
Avg. T _{ambient} , °C	16.3	15.7	13.8	15.0	17.6	21.9
Maximum T _{ambient} , °C	41.7	42.4	40.5	29.9	34.5	40.5
Avg. wind speed, m/s	3.0	2.9	3.0	3.1	3.1	3.2
Max. wind speed, m/s (sustained 10-min.)	15.1	13.6	14.0	10.5	11.8	9.8

PVUSA DAVIS **RECENT MONTHLY INSOLATION**

Figure III.5

3. Operation and Maintenance

Table III.5 summarizes PVUSA's Davis O&M activities. This summary does not include Data Acquisition System (DAS) O&M activities. Host system O&M activities are described along with host system performance in the following section of the report. The activities are identified as either preventive maintenance (including planned outages), failure-related (including forced outages), or research activities.

**Table III.5
2nd Quarter 1994 O&M Summary**

O&M Type	Event	Date; Force x Time (default is 1 person)
Preventive	<u>Site-BOS:</u> Read meters and report to PG&E Control Dept. Check fire extinguishers, emergency lights, security system; maintain site vehicles, garbage/recycling, lubricate sump pumps. Check safety boxes and perimeter fence. Vegetation control Major cleaning of visitors center and I&C building <u>APS:</u> Clean PCU filters, adjust operating limits. <u>IPC:</u> Clean PCU filters, set tracker clock, check MOV fuses. <u>ENTECH:</u> Lube and calibrate tracking system, check battery. <u>EMT-1:</u> Inspect array and adjust PCU operating limits.	Monthly; 1/2 hr Monthly; 4 hrs. Quarterly; 2.5 hrs. Quarterly; 20 hrs + \$980 Annual; 20 hrs + \$450 Monthly; 1 hr Monthly; 1.5 hrs. Monthly; 2 hrs Quarterly; 15 hrs total
Failure-related	<u>Site-BOS:</u> (1-1/4 hrs total) Replace site well pressure tank Reset plant after loss of site power <u>APS:</u> (10-1/2 hrs total) Reset PCU due to loss of site power Manually start inverters that did not wake up Adjust drifting dc operating voltage on Inverter 4 Reset inverters that shut down during the day Replaced dc contactor in Inverter 4 Inverter 4 repair by APS Inspect array to identify cracked modules <u>IPC:</u> (18.5 hrs total) EPROM replacement by Omnion Replace repaired Master Control board Reset tracking system Replaced I/O modules in tracker controller system Reset PCU after "DC Overvoltage" and "Abort Power" shutdowns Bridges 4 and 5 failed. Inverter out of service. <u>EMT-1 ENTECH:</u> (5.15 hrs total) Reset/troubleshoot tracker problems Replaced tracker controller board Replaced solid state relay in tracker controller box Reset PCU due to sync error shutdown <u>EMT-1 SSI:</u> (1/2 hr total) Reset PCU due to sync errors <u>EMT-1 Solarex:</u> (5 hrs total) Reset PCU due to frequency error shutdown Replaced circuit board to correct frequency errors <u>EMT-1 UPG:</u> (1/4 hr total) Reset PCU due to sync error shutdown	3/31; subcontractor \$1800 2 occurrences; 1-1/4 hrs total 4/12; 1 hr 2 occurrences; 3/4 hr total 2 occurrences; 3/4 hr total 2 occurrences; 1/2 hr total 4/5; 2 x 1/2 hr 6/7; 3 hrs 5/24; 3-1/2 hrs 4/25; 1/2 hr 4/12; 1/2 hr 2 occurrences; 1/2 hr total 6/25; 1 hr + \$36 46 occurrences; 13 hrs total 5/25; 3 hrs 5 occurrences; 3.65 hrs total 4/25; 1/2 hr 4/5; 1/2 hr + \$18 4/7; 1/4 hr total 4/18, 5/9; 1/2 hr total 11 occurrences; 4.5 hrs total 6/24; 1/2 hr 4/1; 1/4 hr
Research Activities	Take I-V curves of APS test sections	5/2,5/24; 1.5 hrs total

IV. OTHER PVUSA SITES

1. Summary

Figure IV.1.a shows the location and lists basic information about PVUSA's various sites. In addition to the Davis and Kerman sites within PG&E's service territory, host systems are in operation in Kihei, HI, Austin, TX, Farmingdale, NY, Maspeth, NY, and SMUD's 200-kW system in Sacramento, CA began operation in April. Virginia Power's 20-kW system remains on hold in North Anna, VA. The Public Service Co. of Colorado, the U.S. Department of Defense, and Central & South West Services plan to install Utility Scale systems ranging from 50 to 150 kW in 1994/1995.

At a glance, Figure IV.1.b compares how much insolation the various sites have been receiving - and how well their systems have been using it. Two key statistics are presented: this year's cumulative global horizontal insolation, expressed as the average insolation per square meter per day; and this year's cumulative performance index, or the percentage of actual vs. expected generation from each system. Factors such as unplanned outages, soiling, shading, spectral variations, and PCU losses result in a lower performance index. The performance index is not affected by externally caused outages, low insolation, temperature extremes, or even long-term degradation, if an updated PTC rating has been calculated and used.

Figure IV.1.b shows that through the first half of 1994, the average daily insolation at the Davis, Maui, and Kerman sites has been similar, while the daily insolation at the Austin, Farmingdale, and Maspeth sites has also been similar, but about 20% less than at the better sites. Performance indices of 90% or greater are generally indicative of good system performance, a level attained by 6 of the 12 systems monitored (data for the SMUD system is not yet available). Of the remaining 6 systems, all except for the IPC system at Davis have operated at at least an 80% level so far this year. The IPC system continues to experience repeated PCU failures that have limited its actual generation to 29% of its expected value.

The following subsections include detailed performance information for operating sites and status information for those sites under construction.

PVUSA SITE DATA

(as of 7/94)

Figure IV.1.a

PVUSA SITES: CUMULATIVE 1994 SYSTEM PERFORMANCE & INSOLATION COMPARISONS (through June 1994)

INSOLATION: GLOBAL HORIZONTAL, CUMULATIVE 1994 DAILY AVERAGE

Figure IV.1.b

2. Kerman

Tables IV.2.a and IV.2.b summarize 1993 and second quarter 1994 PV system, solar insolation, and weather data for the Kerman site. Figure IV.2 compares the monthly generation and insolation, beginning with the system's first full month of operation in July 1993.

Although it was not noted in the first quarter report, Kerman efficiency values (including 1993 results) were adjusted downward last quarter by 2.6% to account for a discrepancy in previous calculations of total module area. The correct area is 5210 m².

The Kerman system continued to operate well, demonstrating a daytime availability and performance index of 92% for the quarter. Maintenance activities for the Kerman site are summarized above in section II.3.

Table IV.2.a
Kerman Performance Summary

SSI system characteristics	
Rating:	498 kW ac
Installation date:	6/93
Total module area:	5210 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1993 (Jul-Dec)	Cumul. 94	Apr 94	May 94	Jun 94
Availability %	92	93	95	94	87
Ac kWh (incl. start-up)	647626	568395	95720	131002	145389
Ac eff. %	8.9	9.3	9.3	9.1	9.1
Cap. fac. %	23.3	26.3	26.7	35.4	40.5
Max. ac kW	518	533	509	531	533
Wtd. avg. T _{module} °C	42	41	41	45	50
POA insol. (PCU on) kWh/m ²	1107	1163	198	278	308

Table IV.2.b
Kerman Solar/Weather Summary

Quantity	1993 (Jul-Dec)	Cumul. 94	Apr 94	May 94	Jun 94
1-axis insol. kWh/m ²	1317	1284	255	293	344
Horiz. insol. kWh/m ²	895	939	184	215	238
LT-Avg. horiz. insol. kWh/m ²	967 (Jul-Dec)	1006	198	243	258
Peak 1-axis irradi. W/m ²	1177	1221	1132	1221	1137
Peak horiz. insol. W/m ²	1223	1205	1136	1205	1110
Min. T _{amb} °C	-2.7	0	8	8	8
Avg. T _{amb} °C	19.5	17	18	21	25
LT-Avg. T _{amb} °C	19 (Jul-Dec)	15	16	20	23
Max. T _{amb} °C	42.5	42	35	36	42
Avg. wind speed m/s	2.4	2.9	3.3	3.2	3.5
Max. wind speed m/s	10.6	11.4	7.8	7.9	7.8

PVUSA KERMAN SSI US-2 SYSTEM PERFORMANCE INDEX, ENERGY, & POA INSOLATION

PERF. INDEX = ACTUAL / EXPECTED OUTPUT
EXPECTED = f(Insol, temperature, rating)

Figure IV.2

3. Maui

Table IV.3.a summarizes 1992 and 1993 annual and second quarter 1994 performance for the Maui Sovonics array, and Table IV.3.b summarizes solar/weather data. The Maui system's quarterly performance was somewhat poorer than it has demonstrated over the past year. There were a couple of system trips of unspecified cause in May that resulted in about one week of downtime. There was also some downtime and reduced output in June due to one or more module failures. No report was received from Maui Electric this quarter on their maintenance activities. PVUSA has not yet resolved the continuing problem of seemingly high ambient temperature measurements at this site.

Table IV.3.a
Maui Performance Summary

Sovonics array characteristics	
Rating:	18.5 kW dc, 17.6 kW ac
Installation date:	10/89
Total module area:	497 m ²
Orientation:	22° tilt, south facing

Quantity	1992	1993	Cumul. 94	Apr 94	May 94	Jun 94
Availability %	73	85	82	89	77	70
Ac kWh	28085	32405	15172	2986	2546	1938
Dc eff. %	3.4	3.3	3.4	3.4	3.4	3.0
Cap. fac. %	18.2	21.0	19.8	23.6	19.4	15.3
Max. ac kW	18.7	18.5	18.9	17.9	17.9	16.6
Wtd. avg. T _{module} °C	44	44	43	42	45	46
POA insol.(PCU on) kWh/m ²	1812	2131	989	188	161	142

Table IV.3.b
Maui Solar/Weather Summary

Quantity	1992	1993	Cumul. 94	Apr 94	May 94	Jun 94
POA insol. kWh/m ²	2148	2180	1044	188	180	171
Horiz. insol. kWh/m ²	2070	2098	1036	197	206	201
Peak POA irradi. W/m ²	1238	1250	1220	1220	1154	1138
Peak horiz. irradi. W/m ²	1281	1252	1257	1210	1257	1241
Min. T _{amb} °C (Jun-Jul '93 n/a)	15.7	14.8	13.0	16.4	18.1	19.6
Avg. T _{amb} °C (Jun-Jul '93 n/a)	28.2	27.0	26.3	26.4	27.9	28.7
Max. T _{amb} °C (Jun-Jul '93 n/a)	42.7	40.2	41.8	39.3	40.6	41.8
Avg. wind speed m/s	3.7	3.7	3.7	4.2	3.3	3.4
Max. wind speed m/s	13.3	13.1	14.4	12.6	10.5	12.4

4. Austin

Table IV.4.a summarizes 1993 and second quarter 1994 performance for the Austin IPC system. Table IV.4.b summarizes solar/weather data. The Austin system's quarterly availability decreased from 83% during the first three months of 1994 to 75% this quarter. The system was down for several days in May and June due to PCU trips of unknown cause. No maintenance activities were reported.

Table IV.4.a
Austin Performance Summary

IPC system characteristics	
Rating:	17.9 kW ac
Installation date:	7/92
Total module area:	212 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	1993	Cumul. 94	Apr 94	May 94	Jun 94
Availability %	73	78	83	68	73
Ac kWh	27790	14383	2851	2263	3085
Ac eff. %	8.1	8.3	8.2	8.1	8.0
Cap. fac. %	17.7	18.5	22.1	17.0	23.9
Max. ac kW	20.0	19.8	19.8	19.5	19.3
Wtd. avg. T _{module} °C	41.0	38	39	43	50
POA insol. (PCU on) kWh/m ²	1617	820	163	131	182

Table IV.4.b
Austin Solar/Weather Summary

Quantity	1993	Cumul. 94	Apr 94	May 94	Jun 94
POA insol. kWh/m ²	1955	903	164	171	222
Horiz. insol. kWh/m ²	1615	759	138	148	188
LT-Avg. horiz. insol. kWh/m ²	1700	850	152	179	196
Peak POA irradi. W/m ²	1187	1171	1089	1134	1171
Peak horiz. irradi. W/m ²	1193	1181	1074	1141	1181
Min. T _{amb} °C	-1.2	-1.8	6.3	12.1	24.3
Avg. T _{amb} °C	22.6	21.5	23.2	26.5	31.7
LT-Avg. T _{amb} °C	20.0	18.2	20.3	24.0	27.6
Max. T _{amb} °C	41.9	42.8	35.7	39.6	42.8
Avg. wind speed m/s	1.8	2.0	2.4	1.7	2.1
Max. wind speed m/s	7.7	9.2	7.0	9.2	7.5

5. NYSERDA

Table IV.5.a summarizes the system's second quarter 1994 performance. A PVUSA test condition (PTC) rating has not yet been calculated for this system. PVUSA intended to use data from this past quarter to calculate a rating. However, based on the available irradiance profiles from this quarter, it appears as though the system's tracker is not operating. The system's ambient temperature measurements are also in error, and so the rating will be postponed until these problems are resolved. In the meantime, the 17.9 kW rating for the identical Austin system will be used. No maintenance activities were reported for this site. The system has been shut down due to a PCU error since mid-June, and was still down as of early August. Table IV.5.b summarizes solar/weather data.

**Table IV.5.a
NYSERDA Performance Summary**

IPC system characteristics	
Temporary rating:	17.9 kW ac
Installation date:	8/93
Total module area:	212 m ²
Orientation:	Horiz. N-S single axis trkr.

Quantity	Cumul. 94	Apr 94	May 94	Jun 94
Availability %	68	81	86	64
Ac kWh	11332	2143	3247	2632
Ac eff. %	8.5	8.5	8.6	8.1
Cap. fac. %	14.6	16.6	24.4	20.4
Max. ac kW	23.4	19.5	20.2	18.6
Wtd. avg. T _{module} °C	28	28	31	39
POA insol. (PCU on) kWh/m ²	631	119	177	153

**Table IV.5.b
NYSERDA Solar/Weather Summary**

Quantity	Cumul. 94	Apr 94	May 94	Jun 94
POA insol. kWh/m ²	707	119	177	201
Horiz. insol. kWh/m ²	696	140	176	183
LT-Avg. horiz. insol. kWh/m ²	707	138	165	170
Peak POA irradi. W/m ²	1097	1008	1085	1092
Peak horiz. irradi. W/m ²	1053	962	1053	1006
Min. T _{amb} °C	n/a	n/a	n/a	n/a
Avg. T _{amb} °C	n/a	n/a	n/a	n/a
LT-Avg. T _{amb} °C	9.2	10.9	16.6	21.9
Max. T _{amb} °C	n/a	n/a	n/a	n/a
Avg. wind speed m/s	1.8	1.9	1.8	2.1
Max. wind speed m/s	12.4	6.9	7.0	7.5

6. NREL/NYPA

Table IV.6.a summarizes the system's second quarter 1994 performance. Table IV.6.b summarizes solar/weather data. There were no maintenance activities reported for the quarter. Until a PTC rating is established, PVUSA will use NREL's temporary rating of 17.0 kW_{ac}. PVUSA plans to use data from this past quarter to calculate a PTC rating. This work has not been done yet, but should be completed for the next quarterly report.

Table IV.6.a
NREL/NYPA Performance Summary

IPC/Uni-Solar system characteristics	
Temporary Rating:	17.0 kW _{ac}
Installation date:	7/93
Total module area:	413 m ²
Orientation:	Fixed 10° tilt, south-facing

Quantity	Cumul. 94	Apr 94	May 94	Jun 94
Availability %	76	83	79	82
Ac kWh	10523	2240	2616	2702
Dc eff. %	4.0	4.2	4.2	4.1
Cap. fac. %	14.2	18.3	20.7	22.1
Max. ac kW	17.7	16.2	17.7	16.9
Wtd. avg. T _{module} °C	36	31	35	46
POA insol. (PCU on) kWh/m ²	752	149	171	186

Table IV.6.b
NREL/NYPA Solar/Weather Summary

Quantity	Cumul. 94	Apr 94	May 94	Jun 94
POA insol. kWh/m ²	759	149	177	187
Horiz. insol. kWh/m ²	706	142	173	178
LT-Avg. horiz. insol. kWh/m ²	707	138	165	170
Peak POA irradi. W/m ²	1163	1010	1163	1107
Peak horiz. irradi. W/m ²	1050	959	1050	1024
Min. T _{amb} °C	-17.2	4.0	0.0	15.2
Avg. T _{amb} °C	10.6	14.4	17.9	25.7
LT-Avg. T _{amb} °C	9.2	10.9	16.6	21.9
Max. T _{amb} °C	39.2	31.0	35.7	39.2
Avg. wind speed m/s	3.3	3.1	3.3	3.1
Max. wind speed m/s	10.9	9.3	8.8	9.3

7. SMUD

SMUD's 200-kW UPG system at their Hedge substation site in Sacramento, California was brought on line in early April and christened at a dedication ceremony on April 18. This system uses SSI modules mounted on twenty rows of UPG-designed one-axis tracking structures, with power fed to a single Omnion PCU. Although the plant experienced some initial difficulties with frequent PCU trips, the plant is now operating consistently. Performance data are not yet available, as PVUSA and SMUD are in the process of installing and calibrating several remaining data acquisition system signals.

8. Virginia Power (VEPCO)

The data acquisition system installation for VEPCO's AstroPower EMT-2 array was completed in April. As of May, the system was reported to be nearing start-up, but further details were not available.

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