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***Final Report to the
Sustainable Energy Development Council***

**3M Austin Concentrating Photovoltaic Plant
Two-year Performance Report, 1992 - 1993**

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I. Project Description

The US. Department of Energy, the state of Texas, 3M and the City of Austin Electric Utility (the Utility) jointly funded the installation of a nominal 300 kilowatt concentrating solar photovoltaic system above the parking garage of the new 3M facility in Austin. Construction was completed, plant operations began and performance data became available in June 1990. The contributors to this project are listed as follows:

Contributor	Amount
3M	\$ 600,000
US DOE	\$ 743,764
City of Austin Utility	\$ 600,000
State of Texas	\$ 125,000
Total	\$2,068,764

In 1986 the Utility and 3M independently carried out detailed analyses to determine the break-even value for the project. Each partner determined that the project would be cost effective at about \$2 per watt. 3M and the Utility committed to \$600,000 each in April 1988. To make the project move forward the US DOE and the state of Texas contributed the remaining costs. The original design called for the PV plant to be ground mounted. A suitable site on the 3M property was not located and it was determined that the PV would be installed on the roof of the parking garage attached to a steel super structure. Cost increases associated with the roof mounting design and module manufacturing raised the total cost to over \$3 million for the project.

3M company produced the fresnel lenses for the module design and Entech, Inc. of Dallas designed and installed the plant. Based on the cost share, the Utility maintains 31 % ownership in the plant, and 3M 69 %. The energy production and maintenance costs are shared according to the ownership percentages. 3M is the project manager for the project and therefore carries out the daily maintenance and operating procedures and the Utility contributes accordingly. A rigorous monitoring system using a Campbell data logger donated by Sandia National Laboratories was installed to electronically record plant performance on a 10-minute continuous basis.

The data indicate that this project is an ideal "load leveling" scheme for the Utility and reduces peak demand for 3M. These benefits occur because the solar plant produces energy during the peak period of the day, and then 3M buys electrical energy from the Utility at night helping to build our "off-peak" load. (Refer to the drawing below.) When the system operates according to design, 3M saves on peak demand charges and the Utility helps defer the need for future power plant additions. The plant produces approximately 250 MWh per year, with a peak output of about 250 kilowatts ac.

II. Project Specifications

LOCATION: Austin Center 3M on Route 2222, Austin, Texas

SPECIFICATIONS:

Design Rating: 300 kW AC at Standard Test Conditions
Field Rating: 248 kW AC at Standard Operating Conditions
System Efficiency: 12.4 % at Standard Operating Conditions
Cell Efficiency: 17.5 % (single crystalline cells)
Array: Concentrating modules using 3M lenses
Orientation: Two axis tracking
Module area: 2006 m²
Circuits: 36 DC source circuit (720 modules)
Inverter: Omnion, 300 kW
Commercial Operation: June, 1990

III. One-line System Diagram

IV. Photograph

V. Energy Production from Solar Plant - Metered Values

Year	Acc. kWh	Total Annual Insolation (kWh)	% Efficiency	Total Value (\$)
1992	250690	2542800	10%	2758
1993	253460	2600360	10%	2788

Notes:

1. *MMBTU = million BTU
2. Gas savings based on average heat rate of 11,000 BTU/kWh for Austin Gas plants.
3. The Direct Normal Insolation (DNI) is the total solar energy striking the lens surface area throughout the year in kWh recorded by the NIP.
4. The efficiency is a yearly value based on the DNI and the lens surface area of 2006 square meters.

A detailed summary of the plant performance for 1992- 1993 is shown in attachment 1.

VI. Plant Operating Performance - Years 1992-1993

Year 1992

- Operation and maintenance costs were higher than expected due to a design change in the modules. The ground faults in individual modules were repaired.
- Maintenance costs ranged from \$0.01/kWh to \$0.04/kWh.
- The plant produced 250,690 kWh of energy. This energy was either used at the 3M site, or was sent to the Austin Utility distribution system.

Year 1993

- Operation and maintenance costs were very low for the year 1993 at a total of \$2,769 for parts and labor. This translates to a cost of \$0.01/kWh.
- The plant produced 253,460 kWh of energy. This energy was either used at the 3M site, or was sent to the Austin Utility distribution system..
- Degradation of paint on the steel super structure and tracking mechanism has been a major O&M issue. It is theorized that the performance could be affected by the loss of paint due to overheating of the tracking mechanism steel.
- Tracking accuracy was adjusted by resetting the clock timer, a minor nuisance.
- Otherwise, the plant operation was highly reliable and associated with low O&M.

VII. Technology Transfer (Presentations, tours, papers)

PRESENTATIONS

March 19, 1991	Twenty five (25) mechanical engineering students of the University of Texas at Austin, Dr. Gary Villet's Class
February 19, 1992	SOLTECH 92, "Demand-side Management Applications" an Analysis of Austin's Three Systems, the 3M plant, Youth Hostel, and ECHO village. Presenter: John Hoffner
January 15, 1992	San Antonio Chapter of the American Society of Mechanical Engineers (ASME), "Concentrating Photovoltaic Solar Power Plant at 3M/Austin", Presenter: John Hoffner
February 12, 1993	Central Texas Builders Conference, 1993 - Presenter: John Hoffner
February 19, 1993	A mechanical engineering class of the University of Texas at Austin
March 12, 1993	PV for U and the PUC meeting for State Stakeholders
June 16, 1993	Sixty (60) people at Sustainable Building Coalition, monthly meeting, Austin, Texas
September 13, 1993	Utility PV Group, seventy workshop participants

TOURS

March 22, 1990	Seventy five (75) attendees of ASES conference Solar 90 in Austin, Texas - Tour: John Hoffner
January 10, 1991	Ten (10) utility directors of the Texas Public Power Association annual meeting. Tour: John Hoffner
February 19, 1991	Nineteen (19) high school teachers in training, tour set up by Texas Mid-continental Oil and Gas Assoc. - Tour: John Hoffner
May 20, 1991	Twenty three (23) members of the "Association of Women Utility Engineers", Tour: John Hoffner
June 24, 1991	Twenty (20) students from Concordia College, Austin, TX Tour: John Hoffner
January 22, 1992	Twenty Two (22) members of the IEEE Photovoltaics Standards Coordinating Committee - Tour: John Hoffner
February 8, 1992	Sixteen (16) high school teachers in training at University of Texas at Arlington, tour set up by Texas Mid-continental Oil and Gas Assoc. - Tour: John Hoffner
March 8, 1993	Eight (8) visitors from Japan, researchers, and utility representatives
March 18, 1993	Thirty five (35) members of the Learning Activities for Mature People (LAMP)
March 26, 1993	Six (6) visitors from China, researchers and government
April 19, 1993	Twenty seven (27) representative from the Texas PUC and OPC
November 7, 1993	Twenty five (25) attendees of the TX-SRS annual meeting

PUBLICATIONS AND VIDEOS

Date	Organization
March, 1990	<u>The 1990 Photovoltaic Annual Systems Symposium. (SOLTECH), Austin, Texas, "300-KW Concentrating Photovoltaic Plant at 3M/Austin Center", Authors: John Hoffner, Carlos Garcia-Velez.</u>
August 12, 1990	<u>Proceedings of Inter society of Energy Conversion Engineering Conference (IECEC), Reno, Nevada. "Construction and Start-up of the 3M/Austin Concentrating Photovoltaic Plant", Authors: John Hoffner, Carlos Garcia-Velez.</u>
April, 1991	<u>Proceedings of 10th European Photovoltaic Conference, Lisbon Portugal. "Operating Performance of Austin's Two, 300-Kilowatt Photovoltaic Plants" Author: John Hoffner.</u>
August, 1991	<u>Proceedings of American Solar Energy Society, Solar World Congress, Denver, Colorado, "Performance of Austin's 300-Kilowatt Photovoltaic Power Plants" Author: John Hoffner.</u>
November, 1990 VIDEO	VIDEO for distribution and airing on Austin ACCESS TV channels 10, 30 33, a 28-minute documentary video "Solar Photovoltaics - Austin's Silent Power Source" aired on Access TV and has been distributed to societies and individuals in Texas. Producer: John Hoffner

VIII. Lesson Learned from Project

1. Austin is probably not the best location for a concentrating PV plant. Concentrators can only use direct normal insolation (DNI) to operate. Long term data (5 years) taken at Austin's flat-plate site and the 3M site indicate that the direct normal insolation in Austin is only about 60 % of the plane of array insolation for a flat-plate, single access tracking system on an annual basis. Therefore, a concentrating system will only receive 60 % as much usable fuel (solar radiation) compared to a flat-plate system in Austin. An important lesson learned has been - consider the local DNI before installing a concentrating system. Concentrators work well in desert environments as indicated by the PVUSA tests in Davis, California.
2. The roof mounted system added significantly to the cost of the concentrating system. It may be better to install the system on the ground.
3. The original module design used an inadequate sealant on the DC cable connections. The latest Entech design uses a highly flexible epoxy seal that appears to be reducing the water intrusion which was leading to system ground faults.
4. Paint on the steel super structure and module tracking mechanisms has been a continual problem. Paint failure has resulted in rust, which may be causing tracking errors. It has been concluded that in the future the steel should be prepared better before painting, or hot dip galvanized.
5. Nuisance electronic problems with the tracking mechanisms have, on occasion, caused operating failures, and production losses until it is manually reset. Improvements in the tracking controls have been included in Entech's latest designs.

Attachments

1. 3M PV System Annual Performance Report Summary: 1992 and 1993
2. 3M PV System Total Monthly Gross AC Energy and Total Monthly Direct Normal Insolation (in the Array Aperture Area) for 1992
3. 3M PV System Total Monthly Gross AC Energy and Total Monthly Direct Normal Insolation (in the Array Aperture Area) for 1993
4. 3M PV System Total Monthly Gross AC Energy for 1992 and 1993
5. 3M PV System Total Monthly Capacity Factor and 90%-Peak Capacity Factor for 1992
6. 3M PV System Total Monthly Capacity Factor and 90%-Peak Capacity Factor for 1993

Attachment 1

3M PV System
ANNUAL PERFORMANCE REPORT SUMMARY FOR 1992

PERIOD	Jan-92	Feb-92	Mar-92	Apr-92	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Annual
Total monthly gross ac energy, (kWh/month)	9697	19315	21903	21931	14180	27739	28769	26886	27854	24889	19324	9014	250691
Total monthly (24 hr) capacity factor, (%)	5%	11%	12%	12%	8%	16%	16%	15%	15%	13%	11%	5%	13%
Daylight hours capacity factor, (%)	12%	24%	24%	23%	14%	27%	27%	27%	27%	29%	25%	12%	23%
90% peak capacity factor, (%)	0%	3%	25%	30%	29%	46%	44%	44%	44%	33%	8%	0%	25%
Plant availability, (%)	89%	99%	99%	99%	99%	97%	96%	94%	98%	98%	97%	95%	96%
Missing data, (number of readings vs minute readings)	0	0	0	0	0	0	0	0	0	0	0	0	0
Average ambient temperature, (°C)	9.5	13.9	16.4	19.1	21.3	26.7	27.5	26.4	25.1	21.7	12.8	11.6	19.3
Average daytime ambient temperature, (°C)	21.3	25.9	27.6	28.2	32.7	34.0	34.1	34.4	34.2	30.4	29.3	25.5	28.0
Average daytime wind speed, (m/s)	0.5	1.0	0.8	0.5	0.7	8.0	8.1	8.1	8.2	0.3	0.8	0.4	3.4
Average daily insolation on horizontal, (kWh/m ² /day)	2.3	3.4	4.5	5.2	5.8	6.7	6.1	5.5	4.3	2.9	1.8	0.4	4.5
Average daily direct normal insolation, (kWh/m ² /day)	2.2	2.2	3.1	3.6	2.3	5.1	4.9	4.4	4.2	3.5	1.6	0.3	3.5
Total monthly insolation on horizontal, (kWh/month)	143	196	278	315	311	409	417	378	339	269	175	112	3332
Total monthly direct normal insolation, (kWh/month)	136	130	191	214	143	310	302	280	262	261	213	99	2543
Average daytime cell temperature, (°C)	21	29	33	34	34	47	45	44	43	39	27	19	35
Average module cell temperature, (°C)	69	79	75	74	72	82	79	77	76	75	63	67	82
Average monthly dc efficiency, (%)	8%	16%	12%	17%	11%	10%	10%	11%	10%	10%	10%	10%	11%
POWER CONDITIONING SYSTEM (PCS) DATA													
Average daily AC energy output, (kWh/day)	313	666	707	731	457	925	928	867	902	803	644	291	686
Peak daily AC energy output, (kWh/day)	1166	1516	1577	1668	1309	1427	1475	1579	1516	1417	1411	1265	1648
Average daily AC energy output, (kWh/month)	10748	20808	23509	23753	15927	29771	30932	28831	28927	26771	20791	9891	278651
Total monthly gross AC energy output, (kWh/month)	9697	19315	21903	21931	14180	27739	28769	26886	27854	24889	19324	9014	250691
Average monthly inverter efficiency, (%)	90%	93%	93%	92%	89%	93%	93%	94%	93%	93%	91%	92%	92%
Average monthly ac efficiency, (%)	7%	15%	11%	11%	10%	10%	10%	10%	10%	9%	9%	9%	10%
PCS peak hourly power output, (kWac)	188	190	194	195	174	171	169	179	175	193	204	204	204
The average number of daylight hours per day is --													

SYSTEM RATINGS

At Standard Operating Conditions (SOC) = 24°C kWac

DEFINITIONS

SYSTEM AVAILABILITY is the number of hours in which the plant operated divided by the number of daylight hours in the month.
EFFICIENCY is based on monthly AC or DC energy generation, direct normal insolation, and gross array area (2506 m²).
INVERTER EFFICIENCY is defined as: kWh-ac/kWh-dc

CAPACITY FACTOR is based on monthly AC energy generation, and plant rating of 248 kWac.
DAYLIGHT CAPACITY FACTOR is based on daylight hours only, and plant rating of 248 kWac.

90%-PEAK CAPACITY FACTOR is based on hours in which Cdg load is greater than 90% of the monthly peak load, and plant rating of 248 kWac.
PLANT AVAILABILITY is based on daylight hours where direct normal insolation values are greater than 100 W/m² --

Attachment 1 Cont'd

3M PV System

ANNUAL PERFORMANCE REPORT SUMMARY FOR 1993

	Jan-93	Feb-93	Mar-93	Apr-93	May-93	Jun-93	Jul-93	Aug-93	Sep-93	Oct-93	Nov-93	Dec-93	Annual
PERFORMANCE DATA													
Total monthly gross ac energy, (kWh/month)	10503	14395	21303	24846	26421	16865	32489	33488	24054	20925	16188	13381	253459
Total monthly (24 hr) capacity factor, (%)	6%	9%	12%	13%	14%	9%	18%	18%	13%	11%	9%	7%	12%
Daylight hours capacity factor, (%)	13%	19%	23%	24%	25%	16%	31%	34%	27%	24%	21%	17%	23%
90% peak capacity factor, (%)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plant availability, (%)	97%	98%	99%	97%	98%	97%	95%	94%	93%	97%	99%	94%	96%
Missing data, (number of missing ten minute readings)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENVIRONMENTAL DATA													
Average ambient temperature, (°C)	8.8	11.4	14.8	17.9	21.7	25.5	27.7	28.4	25.7	19.4	12.2	11.7	18.8
Average daytime ambient temperature, (°C)	9.4	11.9	15.6	19.0	22.8	26.6	28.6	29.1	26.6	20.5	12.9	12.2	19.6
Maximum ambient temperature, (°C)	23.6	26.9	27.8	28.8	30.8	32.5	34.7	35.4	34.1	32.5	26.4	22.9	35.4
Average daytime wind speed, (mph)	6.9	8.0	8.2	1.9	1.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	6.3
Average daily insolation on horizontal, (kWh/m ² /day)	2.1	3.0	4.3	5.4	5.7	5.4	7.0	6.6	5.4	3.9	2.7	2.2	4.5
Average daily direct normal insolation, (kWh/m ² /day)	1.9	2.2	3.8	4.3	4.3	2.8	5.1	5.4	3.9	3.2	2.7	2.8	3.5
Total monthly insolation on horizontal, (MWh/month)	128	178	278	323	335	327	437	412	306	246	161	136	3291
Total monthly direct normal insolation, (MWh/month)	121	123	238	257	266	168	318	337	237	201	163	173	2600
SYSTEM PERFORMANCE DATA													
Average daytime cell temperature, (°C)	17	22	29	33	40	40	50	53	48	35	25	21	34
Maximum cell temperature, (°C)	71	68	78	64	80	72	76	79	87	71	65	62	87
Average monthly dc efficiency, (%)	10%	13%	10%	10%	11%	11%	11%	11%	11%	11%	11%	8%	11%
PERFORMANCE RATIO DATA													
Average daily AC energy output, (kWh/day)	339	514	687	770	852	562	1052	1091	802	675	540	423	693
Peak daily AC energy output, (kWh/day)	1453	1501	1656	1840	1687	1402	1549	1460	1389	1549	1452	1264	1840
Average daily AC energy/insolation SOC power, (kWh/m ² /day)	16	27	37	41	45	30	56	58	43	36	29	23	37
Total monthly gross DC energy output, (kWh/month)	11537	15664	22971	24824	26488	18772	34876	35979	25666	22767	17642	14996	273723
Total monthly gross AC energy output, (kWh/month)	18083	14395	21303	21086	26431	16865	32489	33808	24054	20925	16188	13301	253459
Average monthly inverter efficiency, (%)	91%	92%	93%	93%	93%	90%	94%	94%	94%	92%	92%	92%	92%
Average monthly ac efficiency, (%)	9%	17%	9%	9%	10%	10%	10%	10%	10%	10%	10%	8%	10%
PCS peak hourly power output, (kWac)	212	183	213	267	198	168	173	170	190	185	210	213	215
The average number of daylight hours per day is =	10.3	11.0	11.4	12.7	13.5	13.9	13.7	13.1	12.2	11.2	10.5	10.1	12.0

SYSTEM RATING

At Standard Operating Conditions, (SOC) = 248 kWac

DEFINITIONS

SYSTEM AVAILABILITY is the number of hours in which the plant operated divided by the number of daylight hours in the month.

EFFICIENCY is based on monthly AC or DC energy generation, direct normal insolation, and gross array area (2006 m²)

INVERTER EFFICIENCY is defined as: kWh-ac/kWh-dc

CAPACITY FACTOR is based on monthly AC energy generation, and plant rating of 248 kWac.

DAYLIGHT CAPACITY FACTOR is based on daylight hours only, and plant rating of 248 kWac.

90% PEAK CAPACITY FACTOR is based on hours in which City load is greater than 90% of the monthly peak load, and plant rating of 248 kWac.

PLANT AVAILABILITY is based on daylight hours where direct normal insolation values are greater than 100 W/m².

Attachment 2

3M PV System Total Monthly Gross AC Energy and Total Monthly Direct Normal Insolation (in the Array Aperture Area) for 1992

Attachment 3

3M PV System Total Monthly Gross AC Energy and Total Monthly Direct Normal Insolation (in the Array Aperture Area) for 1993

Attachment 4

3M PV System Total Monthly Gross AC Energy for 1992-1993

Attachment 5

3M PV System Total Monthly Capacity Factor and
90%-Peak Capacity Factor for 1992

Attachment 6

3M PV System Total Monthly Capacity Factor and
90%-Peak Capacity Factor for 1993