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21-kW Thin-Film PV Technology Validation—An NREL/Solar Energy Centre of India MOU Cooperative Project

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ABSTRACT

This paper summarizes findings during a one-week (27–31 October 2003) site visit to the Thin-Film Technology Test Bed at India's Solar Energy Centre (SEC) near New Delhi. The U.S. and Indian governments signed a Memorandum of Understanding in March 2000 to undertake a 50-50 cost-shared 21-kW thin-film PV technology validation project to evaluate the performance of thin-film photovoltaic (PV) modules under Indian climatic conditions. This project benefits Indian researchers by giving them experience with cost-effective PV materials, and it benefits the United States because data will be sent to the appropriate U.S. thin-film PV manufacturers for evaluation and analysis. During the visit, NREL personnel engaged in technical discussions regarding thin-film PV technologies with Ministry of Non-Conventional Energy Sources engineers and scientists. Issues included inspecting the newly constructed arrays, discussing better methods of electrically loading the PV arrays, taking I-V traces, and gathering baseline I-V data.

1. Objectives

The purpose of this site visit was for NREL personnel to meet with SEC researchers to engage in technical discussions regarding the five thin-film PV arrays installed at the SEC. Tasks included discussing electrical loading of the arrays, taking I-V traces during the visit, and gathering baseline I-V trace data from June 2003. The visit was timed to coincide with the time of year when the weather is relatively mild and clear so that taking I-V curves would be possible. These five thin-film PV arrays were installed at the SEC to demonstrate that the different technologies perform well in India's hot, humid, and cloudy climate. The SEC site is located at 28˚ 35' N, 77˚ 12' E, and at an elevation of 216 meters. At a 30˚ tilt in New Delhi, daily mean global solar radiation values range from 4.8 kWh/m^2 (July) to 6.9 kWh/m^2 (November). Average monthly temperatures range from 14˚C (January) to 33˚C (June). Average monthly rainfall ranges from 3 mm (November) to 200 mm (July) [1]. SEC researchers are gaining operating experience with the installed PV systems.

2. Technical Approach

Five separate PV systems were installed by Tata BP Solar India between October and December 2002 (Table 1). The Rated Power was determined from the name-plate rating on the deployed modules. The systems are stand-alone because of utility power quality and connection-bureaucracy issues. The arrays charge vented Kirloskar battery banks with 5-kVA AES inverters running various SEC building electrical loads consisting of lamps, fans, PCs, air conditioners, TVs, water coolers, data acquisition systems, etc. All five PV systems became operational May 2003. Baseline IVs were taken June 2003.

The first order of business during the site visit was to inspect the arrays and system installations. Next, I-V curve traces were taken. Finally, NREL and SEC researchers discussed the findings.

Table 1. Overview of SEC PV Arrays

Manu.	Material	Module	# of Modules	Rated Power (W)
BP Solarex	a-Si dual junction	MST-43 MV/R Integra Frame	110	4730
DunaSolar	a-Si dual junction	DS40-L01-S14	93	3720
First Solar	CdTe	FS-50-D Universal Mounting Rails	102	5100
Siemens Solar	CIS	ST40 narrow frame	77	2880
Uni-Solar	a-Si triple junction	US-64	56	3584
			Total Rated Power =	**20014**

3. Results and Accomplishments

The biggest problem noted with the installation of the systems was the array wiring. The installers apparently lacked the proper tools, parts and training in wiring together modules, especially those that did not have "traditional" junction boxes. Otherwise the systems were well installed and seemed to be operating correctly.

SEC researchers complained that all five arrays were operating at low (less than 37%) capacity factors. Capacity factor is defined to be the ratio of an array's actual power output to its expected output. Because the SEC electrical loads vary unpredictably during the day, the capacity factor could not be controlled or determined. The arrays and systems were performing as expected.

The BP-Solarex MST-43 MV/R dual-junction a-Si modules have Integra Frames instead of traditional junction boxes. The installer, lacking instructions in how to wire these modules, did not properly wire the array.

The DunaSolar glass-on-glass DS40-L01-S14 dual-junction a-Si modules have no frames and have two leads suspended from the back instead of junction boxes. The installer, lacking instructions on how to wire modules, did not properly wire the array.

The First-Solar FS-50-D CdTe modules have Universal Mounting Frames that only partially protect the long edges. Although these modules came with reliable Multi-Contact connectors on the end of wire leads, the installers actually cut the connectors from the leads to splice into the array combiner box. These modules do not have junction boxes. There were no signs of corrosion in these modules.

The Siemens-Solar ST40 CIS narrow-frame, glass-on-glass modules have full aluminum frames and junction boxes. The wiring of this array looked neat and acceptable. There were no broken modules and no signs of corrosion.

The Uni-Solar US-64 triple-junction a-Si modules contain no glass, have full aluminum frames and have junction boxes. There were no broken modules or signs of corrosion. The wiring of this array looked neat and acceptable.

Array I-V traces were first taken 24 June 2003. Because an accurate exposure history before this date is not available, this data will serve as the baseline. Baseline I-V data is found in Table 2 [2]. The traces were taken between 11:24 and 12:33 local standard time.

Table 2. 24 June 2003 Baseline I-V Trace Summary

	Irradiance	Rated Array Power	Daystar Measured Power	Tpv	Corrected Measured Power	Corrected vs. Rated Power
	W/m^2	W	W	Deg C	W	%
BP Solarex	772	4730	3063	59	4418	93%
DunaSolar	768	3720	2659	61	3716	100%
First Solar	801	5100	3816	61	5134	101%
Siemens	806	2880	2161	57	3318	115%
Uni-Solar	800	3584	2455	59	3305	92%

The power was corrected for irradiance and module temperature. Maximum-power temperature coefficients, obtained from the manufacturers, are:

- BP Solarex: -0.30%/˚C
- DunaSolar: -0.19%/˚C
- First Solar: -0.20%/˚C
- Siemens Solar: -0.60%/˚C
- Uni-Solar: -0.21%/˚C.

Arrays are cleaned weekly and array tilts are adjusted monthly between 0˚ and 45˚. No signs of abnormality appear in any of the I-V traces.

4. Conclusions and Future Research

As a general observation, arrays employing modules with full frames and junction boxes have held up the best at the SEC. They had no breakage and showed no signs of corrosion. Most wiring problems could have been avoided had the installers been given proper tools, parts, and installation instructions. Poor or improper wiring could lead to system failures and could pose a safety risk to personnel working on the arrays.

SEC researchers are planning to connect electronic loads to a portion of each array in order to control and determine the capacity factor. SEC may then want to do a PVUSA-style analysis of each array's performance, as is done at NREL.

One of the greatest issues facing the SEC Thin-Film Technology Validation Project is the lack of personnel. Just prior to the site visit, one of the two scientists working on the project had been reassigned, and the only engineer quit shortly after the site visit. The one remaining scientist is burdened with many other responsibilities at the SEC. At least one scientist and one engineer should be assigned to the project full time.

NREL and SEC researchers will continue working together to monitor these five arrays and work together with module manufacturers to improve future thin-film PV modules and systems.

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[1] www.worldclimate.com.

[2] P. McNutt. *India Solar Energy Centre Site Visit Final Report*, 18 June 2004. NREL Internal Report.

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