Field Testing of CdTe PV Modules in Mexico

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ABSTRACT

A field performance evaluation was conducted on four First Solar PV water pumping systems in Morelos, Mexico. The objective was to assess CdTe/CdS PV module performance in year round hot and humid climates. Environments that are hot year round, such as in tropical lower Morelos, represent one of the most demanding climates for PV modules and thus are early indicator regions for potential failure mechanisms. These Mexican First Solar systems are among the very few in the world installed in a tropical environment. Most of the systems were new and a baseline was established for future array ratings and degradation trends. The oldest system (2 years) showed a slight de-rate from nameplate, but only of about two percent after two years.

1. INTRODUCTION

The Southwest Technology Development Institute of the College of Engineering at New Mexico State University (NMSU) conducted field tests of First Solar PV modules with the Fideicomiso de Riesgo Compartido (FIRCO) of the Mexican Secretariat of Agriculture and the Universidad Nacional Autónoma de México (UNAM) (Energy Research Lab) in the southern Mexican state of Morelos. Field tests were conducted through March 29-31, 2005. Four sites visited in Morelos state with cadmium telluride PV modules were: Las Margaritas and El Amate in the Hutchilan region, and El Laurel and El Corralito in the Temoac region. First Solar FS55 PV modules were installed on the four of the water pumping systems.

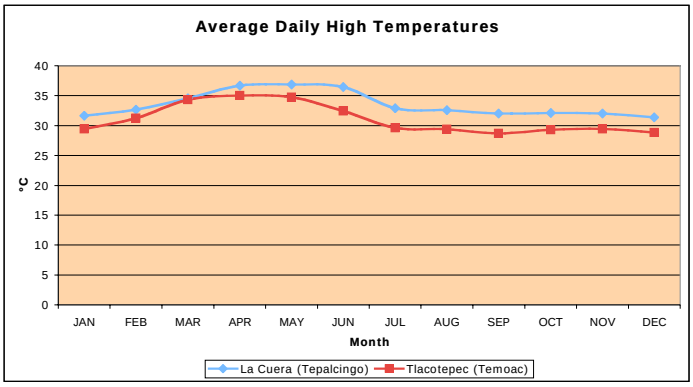

Fig. 1. Average monthly daily high temperatures near First Solar test sites in Morelos, Mexico [1].

In Morelos, climate varies with altitude, from relatively cool pine forests in the mountains, to hot and humid plains at lower elevations. The predominant climate zone throughout the state of Morelos is hot and humid, centered in the lower elevations of the Amacuzac and Nexapa river basins. The zone is dominant in the central and southern parts of the state, bordering both the States of Mexico and Guerrero. PV systems were tested in the hot and humid climate zone of Morelos as defined by INEGI. This climate zone has an annual average temperature above 22ºC, with daytime highs between 30-37°C. The hot climate zones get the most rainfall during the summer, and less in the winter. [1]

2. FIRST SOLAR PV SYSTEMS

2.1 Test Methodology

NMSU and UNAM employed standard field test procedures for evaluating the performance of the Morelos PV systems. In general, systems were field tested as close to solar noon as feasible. The following parameters were typically measured for the different field tests:

- T_m = Back-surface module temperature, °C
- POA = Solar irradiance on plane of array, W/m^2
- Voc = Array and module maximum open circuit voltage, V
- Vp = Array and module maximum peak operating voltage, V
- Isc = Array and module short circuit current, A
- Ip = Array and module maximum peak operating current, A
- Q = pumping flow rate (lpm)

Current-voltage (I-V) curves were taken from the arrays and curves were normalized in order to determine an array power rating. In some cases, I-V curves were taken of the array as found (dirty) and then the array was washed. In a few cases, the arrays were not cleaned since they were late in the day tests and irradiance was low and good tests were not possible. In addition, both dry and wet Megger tests were performed to measure any potential current leakage.

After quantifying irradiance, temperature coefficients, and measured current-voltage characteristics (both manufacterer and Sandia generated coefficients), the I-V curves were normalized to Standard Test Conditions. The IVPC software used with the curve tracer allows for this type of normalization. Temperature coefficients were used for First Solar array normalization based on the reported average values from the module manufacturer [2]. Since a module's response to the direct (beam) component of irradiance is influenced by the cosine of the solar angle-of-incidence and by the optical properties of its front surface, it is important to attempt to take readings as close to solar noon as possible.

Thermal infrared (IR) imaging was also taken of the arrays to illustrate the temperature distribution across the array during operation. Module temperatures appeared to be relatively uniform, with the greatest heating found immediately above the module junction boxes, but typically no more than about 5°C hotter than the average cell temperature.

2.2 First Solar PV Modules

First Solar PV modules were tested. These are made using a heterojunction compound thin semiconductor design incorporating CdTe and CdS materials. The First Solar modules are UL 1703 compliant and IEC 61646 certified. The modules are also warranted for 20 years. They use a front heat strengthened glass 3.2 mm thick laminated to a 3.2 mm back tempered glass. All of the first modules tested were the FS-55 series modules. These modules were made for Grundfos specifications as shown in Table 1 for water pumping systems.

TABLE 1: FS MODULE SPECIFICATIONS [2]

First Solar Module Electrical Specifications (STC)	FS-55
P_{mp}	55 W
V_{mp}	61 V
I_{mp}	0.9 A
V_{oc}	88 V
I_{sc}	1.13 A
Series Fuse Rating	2A
Maximum System Voltage	600 V
T_k P_{mp}	-0.25%/°C
T_k V_{oc}	-0.29%/°C
T_k I_{sc}	+0.04%/°C

3. TEST RESULTS AND DISCUSSIONS

3.1 Huitchila PV Water Pumping Systems

Las Margaritas and El Amate –Tepalcingo
Lat: 18° 38.105 'N, Long: 98° 54.504' W
Altitude: 1150 m

The two PV water-pumping systems are installed next to each other (100 m apart) on two small ranches near the community of Huitchila in Morelos. Both systems are similar in design and workmanship. Overall, out of over 500 PV water pumping systems the authors are familiar with in Mexico, the two Huitchila PV systems represent some of the better quality PV installations

for water pumping found in the country. The total dynamic head for Margaritas is 13.76 m, while for El Amate it is 12.20 m. These first two systems were installed in January 2005 near the community of Hutchilan by José Ramon Sánchez Ceresuela of CRYPLANT from Cuernavaca.. The installed systems are comprised of the following major components:

1) First Solar FS-55 PV modules (6) 55 W_P each, (approx. 330 Wp dc, STC).
2) Grundfos CU200 SQ FLEX Pump Controller
3) Grundfos 11SQF-2 Pump
4) Delta Lightning Arrestor LA302 dc, 600 V Max
5) Moeller FAZ C6 DC 220/250 V breaker

Fig. 2. Huitchila PV Array in Las Margaritas under test by UNAM, NMSU, and FIRCO personnel.

Visual inspection of the arrays found no module delamination or other evident problems. A small manufacturing anomaly was found on one of the modules for Las Margaritas, but it did not affect module performance as noted from its I-V curve. The anomaly appears to be a film scratch caused by handling of the modules by First Solar personnel during the manufacturing process. First Solar claims that their latest product is now produced with newer manufacturing processes, which have virtually eliminated human handling of the product until it is finished and laminated, so these types of scratches are no longer an issue]2]. The scratch found did not affect the performance of the First Solar module.

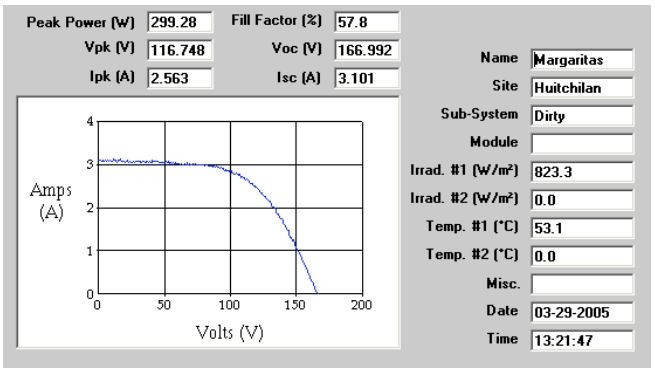

Fig. 3. Huitchila PV Array in Las Margaritas.

Both arrays are mounted on metal painted fixed posts, with the array tilted 20 degrees for Las Margaritas and 22 degrees for El Amate. These are acceptable array tilt angles for Morelos (Lat ~18°N). In Las Margaritas the array is installed with an orientation of 178° magnetic South and the array at El Amate is oriented to 180° magnetic South (the local magnetic declination is about 6° W). In both arrays, the six First Solar PV modules are wired for 2 modules in series and 3 in parallel (2S x 3P). The arrays are wired for a nominal 122 Vdc operation. The Margaritas system was pumping water at the rate of 40 lpm at 840 W/m^2 irradiance with 13.76 m total dynamic head, while El Amate was pumping 41.5 lpm at 650 W/m^2 at 12.2 m totay dynamic head.

Fig. 4. Inconsequential manufacturing film scratch present on one of the Margaritas First Solar PV modules.

Both systems incorporate a Moeller FAZ C6 DC breaker rated at 220/250 V to disconnect the PV array. The disconnect device is located in rainproof enclosure under the array as shown below. A Delta Lightning Arrestor is also used for lightning protection. Array wiring consists of THWN 12 AWG Condulac wire in conduit. All module frames are bonded to ground using 8 AWG copper conductors, as well as the negative conductor. A 3 meter grounding rod was installed at the base of the array.

Fig. 5. Array disconnect using Moeller FAZ C6 DC

Both Huitchila PV water pumping systems were found to be in good condition and within manufacturer specifications and warranties. Arrays were cleaned for testing. Rated power for both systems showed them to be basically at nameplate rating. The irradiance was better for normalization of the Las Margaritas array, and was considerably less for normalization of the El Amate array.

3.2 El Laurel PV Water Pumping Systems, Temoac
Lat: 18° 46.691 'N, Long: 98° 47.845' W,
Altitude: 1545 m

The El Laurel system is probably the oldest First Solar PV array installed in Mexico since March, 2003. As such, it is of the most interest in identifying potential trends. The system was installed by Ingeniería en Riego Agrícola, in the rural region bordering the community of Temoac, Morelos. The system consists of the following components:

1) First Solar FS-55 PV modules (6) 55 W_P each, (approx. 330 Wp dc, STC).
2) Grundfos CU200 SQ FLEX pump controller
3) Grundfos 11SQF-2 pump
4) Delta Lightning Arrestor LA302, 600 V dc max
5) Moeller FAZ C6 DC breaker

The array tilt is 21 degrees, which is an acceptable inclination for Morelos (Lat ~18°N). The array has an orientation of 179° magnetic (the local magnetic declination is about 6° W). The 6 modules are wired 2 modules in series and 3 in parallel (2S x 3P). The arrays are wired for nominal 122 Vdc operation.

The installation showed inferior quality workmanship. The wiring connections were simply twisted and taped together. One module frame bond had loosened as was no longer attached to the frame. Current leakage was found during the wet Megger test since module interconnects are only taped and twisted, this allowed for water intrusion and subsequent current leakage. No delamination or hot spots were detected in any of the modules.

The local FIRCO engineer responsible for acceptance testing, Miguel Valderrabano, advised the test team that the system was not originally accepted as one of the original First Solar modules installed at this site was not functional when installed. The problem was that the module junction box had pulled away from the module frame. When the junction box was pushed hard against the module, the module would work. The module was sent to the Grundfos supplier in Monterrey, Nuevo León, Mexico and replaced under warranty in 2003. This failed module was unavailable for further assessment and no new module failures have occurred.

The system was found to be pumping 41 lpm at an irradiance of about 800 W/m^2. The system had pumped only 335 cubic meters of water since installation according to the totalizing flowmeter. The system is oversized for the water need and the rancher does not constantly use it.

Fig. 6: El Laurel PV Array under test by NMSU and UNAM.

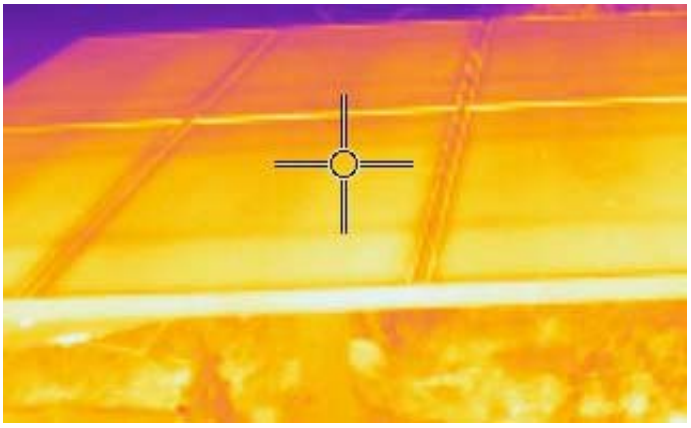

Fig. 7: Infrared images of the El Laurel PV system detected no module hot spots.

Current-Voltage (IV) curves were likewise taken of the El Laurel array as shown. The array was washed for testing. An IV curve was also taken for a single module of the array. The IV curves showed no anomalies that would indicate the presence of any weak or failed modules. The IV curves were normalized to Standard Test Conditions (STC, 1000 W/m^2 irradiance, 25 degrees Celsius module temperature) to determine rated power.

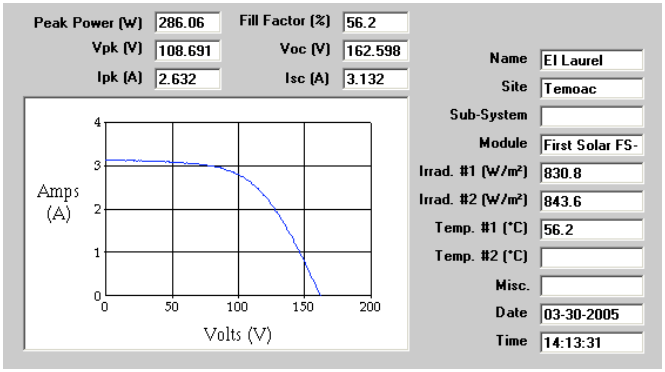

Fig. 8: Typical current-voltage (IV) curve from the El Laurel PV array.

3.3 El Corralito, Municipality of Temoac (Latitude: 18°46.69' N, Longitude: 98°47.84' W, Altitude 1530 m)

The El Corralito First Solar PV system was completed in January 2005 near the community of Temoac in Morelos. The system is comprised of the following components:

1) First Solar FS-55 PV modules (8) of 55 W_P, (approx. 440 Wp dc, STC).
2) Grundfos CU200 SQ FLEX pump controller
3) Grundfos 11SQF-2 pump
4) Delta Lightning Arrestor LA302 dc, 600 V Max.

The El Corralito PV water pumping system serves a small ranch and has a well that is 96 m deep with a water level of about 23 meters. The array is mounted on a painted metal post and tilted at 23 degrees, which is an acceptable inclination for Morelos (Lat ~18°N). The array is installed with an orientation of 164° magnetic (the local magnetic declination is about 6° W). The 8 First Solar modules are wired 2 in series and 4 in parallel (2S x 4P). The arrays are wired for nominal 122 Vdc operation. Despite the hour growing late, system tests were conducted after 4:00 p.m. when the irradiance was low and the sun incidence angles high (i.e., far from perpendicular). Given the late hour and the low irradiance level the uncleaned modules were tested at, the overall system test was inconclusive and no water pump test was coducted. Overall summary test results for all four Morelos PV systems including El Corralito are provided in Table 2.

Fig. 9. El Corralito PV system array.

TABLE 2: FIRST SOLAR MODULE NORMALIZED ARRAY RATINGS FOR 4 SYSTEMS IN MORELOS

First Solar Normalized Array Ratings								
Normalized @ STC: 1,000 W/m^2 and 25 °C								
System/Date Installed	Tilt/ orientation	Size Wp	Isc	Voc	Ip	Vp	Normalized Array Rating	% of nameplate
Las Margaritas (Jan. 2005)	20°/184°	330	3.5	172.1	3.0	115.0	340 ± 17 Wp	102.9 ± 5.0%
El Amate (Jan. 2005)	22°/186°	330	3.8	170.3	3.1	108.4	335 ± 23 Wp	101.7 ± 6.9 %
El Laurel (March, 2003)	21°/185°	330	3.5	170.5	2.9	111.7	323 ± 15 Wp	98.0 ± 4.8 %
El Corralito (Jan. 2005)	23°/170°	440	4.8	167.6	3.7	103.6	384 ± 31 Wp	87.4 ± 8.0%*

4. CONCLUSIONS

The First Solar systems tested in hot and humid Morelos, Mexico showed no significant module problems. Most of the systems were new and a baseline was established for future array ratings and degradation trends. The oldest system showed a slight de-rate from nameplate, but only of about two percent after two years and within measurement error.

First Solar has supplied a total of 300 kWp of modules to Grundfos for their water pumping systems in Mexico. The oldest Grundfos water pumping systems are from early 2003, and one of the Morelos systems tested was of this vintage.

A few of the First Solar modules showed some small manufacturing film scratch anomalies related to production. Small scratches, typically no more than a centimeter in length, were found in only a few cases. However, these had no apparent effect on module output and First Solar states that these types of manufacturing anomalies no longer occur.

The First Solar modules tested on three arrays were relatively new and were found to be in good operating condition. Although these systems were relatively new, obtaining a systems baseline of these systems soon after installation will provide a good benchmark for observing future trends. For the oldest two year old First Solar system at El Laurel, the array was found to be about two percent below nameplate but within measurement error. With the current baseline established, future testing on these systems can more accurately show any module trends.

PV water pumping systems installed under the World Bank/GEF FIRCO Renewable Energy for Agriculture Program have demonstrated that long-term reliability is achievable for this application. The PV systems have proven to be an excellent option in meeting water pumping needs in rural Mexico where electrical grid service does not exist. Investment payback for the PV water pumping systems has averaged about 5-6 years for most ranchers (3).

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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