Solar Edge

First Solar's energy advantage in Indian climatic conditions

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Energy demand is moving from temperate climates like in Europe to the tropics, where there is ample sunlight, and increasing economic activity. These hot and humid climates are ideal for innovative photovoltaic (PV) module technologies like First Solar's. First Solar's thin film cadmium telluride (CdTe) PV modules generate 5-8 per cent higher energy yield in hot, humid climates, primarily due to two factors: lower rate of instantaneous power drop as compared to crystalline silicon (c-Si) when operating temperatures increase; and maintained power output when the spectrum of light shifts as a result of humidity in the atmosphere, due to positively differentiated attributes of First Solar's CdTe semi-conductor. To demonstrate the technology advantage and higher energy yield, showcased in this article are three live cases studies in which both First Solar thin film technology and c-Si technology are co-located with similar project designs.

10 MW Marikal Solar Park

Technology description

There are currently just a few economically viable PV module technologies, each with unique characteristics that are specifically important to understand for successful application in hot humid climates like India. Crystalline silicon modules consist of PV cells (typically of between 12.5 square cm and 20 square cm) connected together and encapsulated between a transparent front (usually glass), and a backing material (usually plastic or glass). First Solar's thin film modules use CdTe as semiconductor material, which is deposited using vapor transport deposition between two sheets of glass. According to Standard Test Conditions, PV modules are evaluated for instantaneous power output (STC) as per IEC 60904-3 1. This standard defines a set of reference conditions at an irradiance level of 1,000 W per square metre and an ambient temperature of 25 °C; less commonly known is that the standard also defines a spectral irradiance distribution characterised by ASTM G173. It is very important to understand that an STC measurement is a single point measurement and does not adequately represent how module performance varies under real world conditions due to real-time changes in field temperature, irradiance levels and spectral irradiance distribution.

The First Solar technology advantage

With more than 17 GW of PV thin film CdTe module technology installed worldwide, solar plants using First Solar thin film PV modules continue to demonstrate consistent performance and reliability advantages. First Solar's high efficiency modules offer a clear energy density advantage over silicon-based modules by delivering similar efficiency, higher real-world energy yield and long-term reliability. First Solar modules feature an innovative design, quality construction and superior performance that excel in the industry's most rigorous extended durability protocols like the Thresher Test, Long Term Sequential Test, and Atlas25+. First Solar cell structure has an improved back-contact design that better manages the fundamental power-output degradation mechanism, which significantly enhances the long-term durability and extended test performance of the modules. First Solar's commercially available 16.7 per cent efficiency modules compete with the best-in-class multicrystalline today. First Solar's module technology roadmap continues to provide a trajectory of future efficiency improvements demonstrated by world-records for thin film PV cells at 21.5 per cent and modules at 18.2 per cent. First Solar modules also offer higher power density with comparable land usage when compared to typical cSi modules, resulting in more installed capacity per square metre.

First Solar CdTe module advantage

CdTe modules deliver more energy in real-world conditions due to following benefits:

- Lower temperature coefficient
- Better spectral response
- Linear response to shading

Higher energy yield in hot conditions

All PV modules produce less power than their nameplate as temperatures rise above their labelled 25°C standard test condition. Whenever module operating temperatures exceed 25°C (this can be >90 per cent of generating hours in hot climates), CdTe modules will produce more energy compared to c-Si modules due to the lower temperature coefficient of power. First Solar's S4v3 module temperature coefficient is -0.28 per cent per degree Celsius, compared to a range of -0.41 per cent per degree Celsius to -0.45 per cent per degree Celsius for typical c-Si modules. On a hot sunny day, module temperatures can reach 65°C, resulting in First Solar modules producing up to 5-6 per cent more power than c-Si modules on average. Over a year in hot conditions, this high temperature advantage can add up to 3-4 per cent more annual energy than c-Si modules.

Higher energy yield in humid conditions due to spectral response advantage

Sunlight is comprised of multiple wavelengths and various intensities of light. The intensity of various sunlight wavelengths that reach the earth's surface is influenced by atmospheric conditions, with water vapor in the atmosphere having the largest effect for CdTe (commonly correlated to high humidity). Different PV technologies respond differently to different light wavelengths. On humid days, water in the atmosphere reduces specific wavelengths of available light. First Solar CdTe modules are less sensitive to reductions in wavelengths most affected by this type of high atmospheric water content. This superior spectral response allows First Solar modules to produce up to 4-5 per cent more annual energy in high humidity conditions.

Higher energy yield due to better shading response

CdTe modules minimize power loss from shading because of a unique cell design. When a CdTe module is shaded, only the shaded portion is impacted, while the rest of the module will continue to produce power. This is in contrast to typical c-Si modules that use bypass diodes to turn off disproportionately large portions of the module when shading occurs to protect the device from damage. In an environment with 10 per cent shading, a standard c-Si module will lose up to 30 per cent of its power while a First Solar module will only experience a 10 per cent loss of power under the same conditions.

Live project studies to validate First Solar's energy advantage in hot and humid Indian climate

The anticipated energy yield advantage of First Solar's modules is up to 6-9 per cent compared to equivalent crystalline silicon (cSi) modules at the same locations. This advantage is of key importance in hot and humid climates such as India, where First Solar's high efficiency thin film modules have an increased energy yield advantage due to a superior temperature coefficient, and better shading and spectral response. This article compares performance of First Solar's thin film CdTe modules with multicrystalline modules under field conditions for three different sets of commercially operating plants. Since full plant information is not publicly available, reference simulations are run at each of these locations in PlantPredict (www.plantpredict.com) using typical system design parameters, illustrating the expected difference in energy output when comparing plants that are designed identically. Then, energy output for each of the three cases is shown, comparing a First Solar plant to a c-Si plant in the vicinity. Additional information summarizing system design parameters indicates how well the energy advantage is expected to match the reference simulations.

Table 1: Modeling parameters for 3 reference cases

	c-Si	FS
Weather file	NSRDB SUNY database	
Soiling	2 per cent	
Spectral	2-parameter model (reference)	
Module	Jinko JKM 290P	First Solar FS-385
Inverter	SMA 800 CP XT	
DC/AC ratio	1.2	
Ground coverage ratio	50 per cent	
Module mounting/angle	Fixed tilt, 25°	
Azimuth	180° (due south)	
Shadings	Linear	
Transposition model	Hay	
Incidence angle	Tabular IAM	
AC collection loss	1 per cent	
Module quality	0 per cent	
Mismatch	1 per cent	
LID	1.50 per cent	0 per cent
DC wiring at STC	1.50 per cent	
Thermal coefficients	29, 0	30.7, 0

Reference simulations

Reference simulations were run in the two locations indicated for the case studies below, using typical plant design parameters as outlined in Table 1. TMY files from the NSRDB SUNY database (https://nsrdb.nrel.gov/international-datasets) were used as this data is publicly available. Module files were used that are indicative of what was available when the systems in case studies 1 and 2 were installed (c-Si modules represented by Jinko JKM 290P compared to First Solar FS-385), although use of newer generations of modules is not expected to change the relative energy difference of the simulations significantly as long as the system design is consistent. System design was kept simple for illustrative purposes, and all losses are equivalent between module technologies excepting LID and thermal coefficients. First Solar modules do not experience LID so this assumption was set to 0 per cent, and the thermal coefficients for First Solar modules have been studied and found to match field performance most closely at 30.7 and 0 (http://ieeexplore.ieee.org/ document/ 6656705/). The latest version of the spectral model (http://ieeexplore.ieee.org/document/ 7749836/) was used for both technologies.

The results of the reference simulations are shown in Table 2. Overall, results at the two locations did not vary significantly, as each had similar temperature and humidity conditions. The greatest energy advantage in these locations is due to temperature, where the gain was on the order of 4-5 per cent. The next biggest difference in the simulations was due to LID, where the c-Si simulation had an additional 1.5 per cent loss due to this effect. The climate represented by these three locations does not exhibit the humid conditions that lead to a large spectral adjustment, so this gain was less than 1 per cent in all reference cases. On average, the energy advantage of First Solar modules in these two locations was 7.7 per cent.

Table 2: First Solar's energy advantage in case study reference simulations

	Case 1	Case 2
Total annual energy advantage (per cent)	7.80	7.80

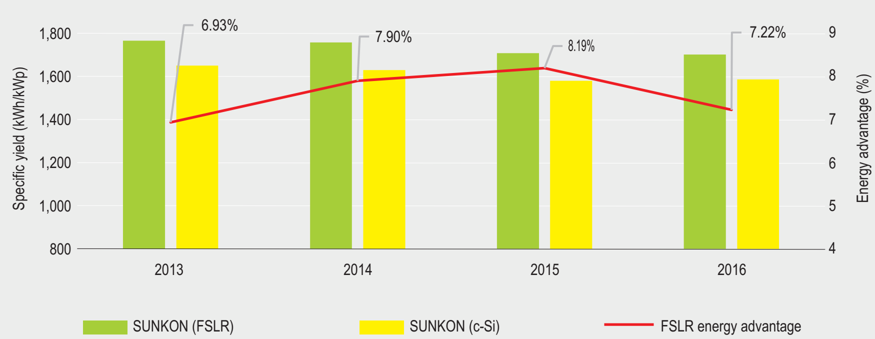
Table 3: Plant design comparison of Sunkon and First Solar projects

Project (Plant)	Sunkon 4.8MW/5 MWp (FS)	Sunkon 4.8MW/5 MWp (c-Si)
Developer	Sunkon Energy Private Limited	Sunkon Energy Private Limited
Module type	First Solar Thin Film (CdTe)	Multicrystalline module
PV plant location	Ghespur village, Jafrabad taluka, Amreli district, Gujarat	Ghespur village, Jafrabad taluka, Amreli district, Gujarat
Latitude (°)	20° 52' 42.17"N	20° 52' 42.17"N
Longitude (°)	71° 16' 46.33"E	71° 16' 46.33"E
EPC contractor	Moser Baer Solar Limited, New Delhi	Moser Baer Solar Limited, New Delhi
Inverter make	SMA (800CP)	SMA (800CP)
AC DC ratio	1:1.04	1:1.04
Type of structure	Fixed tilt (25°)	Fixed tilt (25°)
Inter row spacing	6.3 metre	6.3 metre
Commissioning date	May 25, 2012	December 23, 2012

Table 4: Performance comparison of Sunkon and First Solar projects

Year	SUNKON (FSLR) kWh/kWp	SUNKON (c-Si) kWh/kWp	CUF for FSLR (%)	CUF for c-Si (%)	FSLR energy advantage (%)
2013	1,765.159	1,650.706	19.71	18.43	6.93
2014	1,757.664	1,629.002	19.71	18.27	7.90
2015	1,708.374	1,579.037	19.08	17.63	8.19
2016	1,700.597	1,586.035	18.80	17.52	7.22

Figure 1: Energy advantage of First Solar CdTe plant over c-Si for Sunkon Energy



Case study 1

Two solar plants belonging to Sunkon Energy Private Limited, located in Amreli district, Gujarat, are compared in Table 3. Comparison of these two plants – one with First Solar module technology installed and the other with a c-Si module installed – is based on measured data from the Gujarat SLDC for the calendar year from January 2013 through December 2016 and is given in Table 4.

Based on the last four years of data comparison, as shown in Figure 1, the plant with First Solar modules is producing 6.93 per cent to 8.19 per cent higher generation annually in comparison to the plant with the c-Si modules, averaging a 7.56 per cent higher generation for the last four years. This analysis is purely based on data received from developer/SLDC, and no other correction on account of module cleaning, plant availability, etc. have been made. This energy advantage illustrated in the measured data is within reasonable uncertainty bounds of the reference simulation, which predicted a 7.8 per cent energy advantage for this location. The similar designs of these c-Si and First Solar plants make this a valuable comparison, despite the unknowns in the data stream.

Case study 2

Two solar plants operational for over four years at Surrender Nagar Gujrat are compared in Table 5. Comparison of the First Solar module technology to the multicrystalline module is based on measured data from the Gujrat SLDC for the calendar year 2013, 2014, 2015 and 2016 (through October) and is shown in Table 6. This analysis is purely based on data received from the Developer/SLDC, and no correction on account of module cleaning, plant availability, etc. have been made.

Based on the last four years of data comparison, the plant with First Solar modules has produced 4.1 per cent to 10.63 per cent higher, annual generation, with respect to the multi crystalline modules, averaging a 6.74 per cent of higher generation. The average energy advantage is slightly less, but similar to the reference case value of 7.8 per cent, and well within the bounds of modeling and measurement uncertainty. However, case study 2 has more annual variation in the energy advantage than the previous case, suggesting that there is likely something not represented in the reference simulations that is affecting the comparison of these two power plants, such as plant availability or soiling effects.

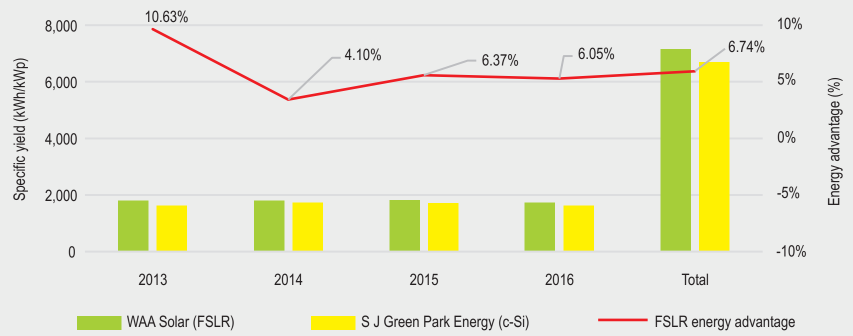
Table 5: Plant design comparison of Waa Solar and First Solar projects

Project (Plant)	WAA 10 MW/10.25MWp	SJ Green 5MW/5.121 MWp
Developer	WAA Solar Private Limited	S J Green Park Energy Private Limited
Module type	First Solar Thin Film (CdTe)	Multicrystalline module
PV plant location	Surendra Nagar village, Tikar, Gujarat	Surendra Nagar village, Tikar, Gujarat
Latitude (°)	23°23?05"N	23°23?05"N
Longitude (°)	70°36?01"E	70°36?01"E
EPC contractor	Madhav	Madhav
Inverter make	SMA (SC720CP)	Bongfiglioli (Vectron)
Type of structure	Fixed tilt (25°)	Fixed tilt (25°)
AC DC ratio	1:1.025	1:1.024
Commissioning date	January 13, 2012	December 16, 2012

Table 6: Performance comparison of Waa Solar and First Solar projects

Year	WAA Solar (FSLR) kWh/kWp	S J Green Park (c-Si) kWh/kWp	CUF for FSLR (%)	CUF for c-Si (%) (%)	FSLR energy advantage (%)
2013	1,797.3	1,624.6	20.50	18.50	10.63
2014	1,803.0	1,732.0	20.60	19.80	4.10
2015	1,818.3	1,709.4	20.80	19.50	6.37
2016	1,723.2	1,624.9	19.70	18.60	6.05

Figure 2: Energy advantage of First Solar CdTe plant over c-Si for Surendra Nagar plants of Waa Solar and S.J. Green



Conclusion

Comparisons of two sets of commercially operating power plants in India demonstrate a consistent First Solar module energy production advantage when compared to similarly designed c-Si module power plants. With identical plant design, reference simulations indicate an energy advantage of 7.44 per cent-7.8 per cent, which could result in additional increase in a more humid climate, where the spectral shift gain is larger. While a comprehensive analysis of individual contributors is not included due to restrictions on detailed performance data, it is reasonable to infer that the temperature response and spectral response advantages of First Solar's modules are significant contributors to specific energy yield and CUF advantages, as indicated by the reference simulations for these locations.

While module efficiency identifies the power produced by a module in a single point at standard test conditions, the specific annual energy yield metric gives a more useful picture of the annual energy produced by the DC array in a power plant under real world conditions. When evaluating return on investment (RoI) for a solar power plant, specific energy yield has one of the biggest impacts on the overall levellised cost of electricity (LCoE). First Solar's high efficiency modules are proven to deliver more usable energy per nameplate watt than conventional silicon-based modules. This means that for an equivalently designed and installed power plant, priced at the same $/Watt, a First Solar plant based on CdTe module technology will produce more energy, resulting in a lower LCoE ($/MWh). ■

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