Fixed-tilt versus single-axis tracker arrays in India

Trackers | India has become the the world's second largest market for trackers as it chases its ambition of installing 100GW of solar by 2022. Geoffrey S. Kinsey, Madhusudan Partani, Mukund Kulkarni, Brijit Shetty, Rubin Sidhu and Jie Zhang report on efforts to better understand the performance benefits of trackers over fixed-tilt mountings

Looking north at 22MW of fixed-tilt and 3MW of tracker arrays in Andhra Pradesh, India

For ground-mounted PV systems, the path to higher generation and availability is paved with trackers. To deliver a higher return on investment as well, the additional generation revenues from trackers need to more than offset the higher costs in equipment, installation and operations and maintenance (O&M). Estimates vary, so uncertainty in these variable costs increases the risks of investment and slows deployment.

Nowhere is understanding the cost/benefit tradeoffs more critical than in India, with over 20GW of PV installed and now the world's number two market for trackers [1]. Precise data on the performance from fixed racks versus trackers is, however, somewhat elusive. At one plant in southern India, trackers co-located with fixed-rack arrays have shown enhanced energy yield of more than 15%.

The 25MW plant shown in the main image was commissioned in 2016 with approximately eighty thousand Hareon Solar 72-cell multi crystalline silicon modules, connected to 31 inverters of about 800kW each, four of which convert energy for the tracker block located in the center of the site. The single-axis trackers are aligned horizontally on a north-south axis; the fixed-tilt arrays are south-facing to within a few degrees of the local latitude (15.6°).

Performance

The power output of the fixed-tilt and tracker arrays is compared in Figure 2. As seasonal variation follows the symmetries of the annual solar cycle, data is grouped by "solar season", where seasons 1 and 3 are centred on the vernal and autumnal equinoxes and seasons 2 and 4 are centred on the summer and winter solstices, respectively. Seasons 2 and 3 are characterised by higher peak power outputs and, for the tracker arrays, occasional inverter clipping. Seasons 1 and 4 present lower peak powers, but also less variability due to clouds, since India's monsoon typically runs from May to September. Around the winter solstice (season 4), the modules mounted horizontally on trackers obtain peak powers below that of the modules tilted southward. Year-round, the squarer shoulders of the tracker output indicate more consistent grid support throughout daylight hours.

The daily plane-of-array irradiation for the fixed-tilt and tracker arrays was used to calculate the "measured" performance ratios in Figure 3. The "expected" performance ratio for the tracker arrays uses the rated module powers and measured site conditions: daily plane-of-array irradiation and the irradiance-weighted module

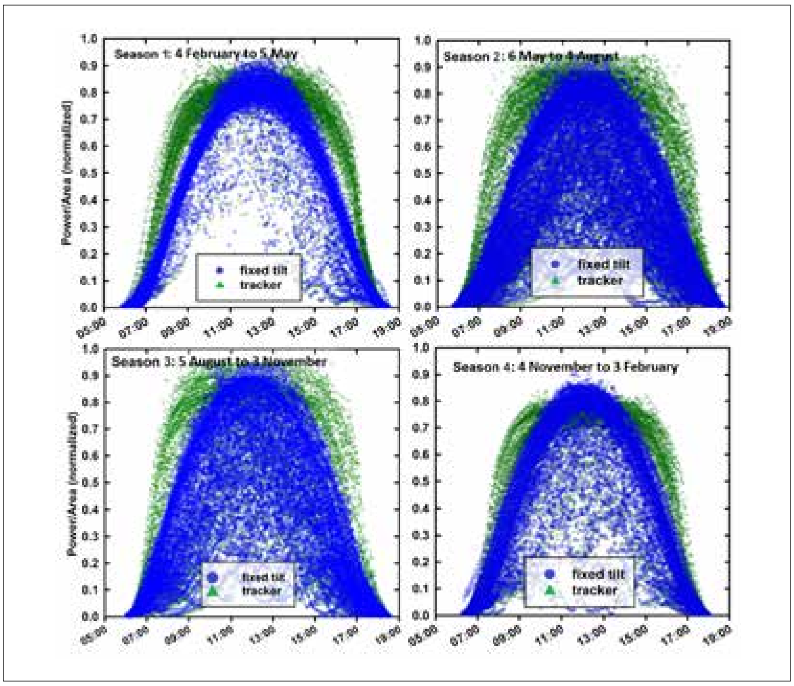

Figure 2. Seasonal variation in AC power output (five-minute mean values)

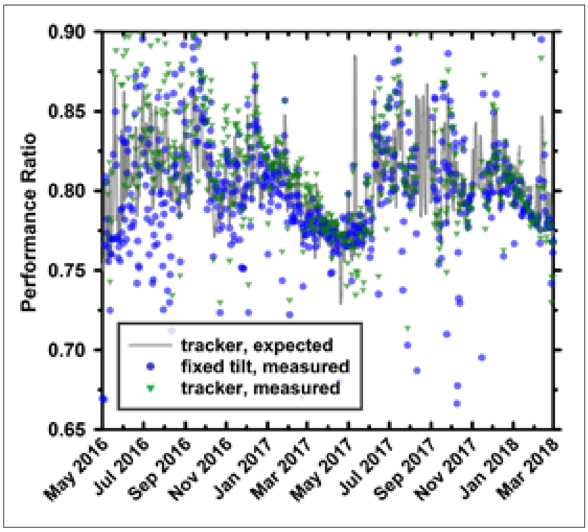

Figure 3. Daily measured DC performance ratios compared against that expected from the tracker plane-of-array irradiance and the irradiance-weighted module temperature

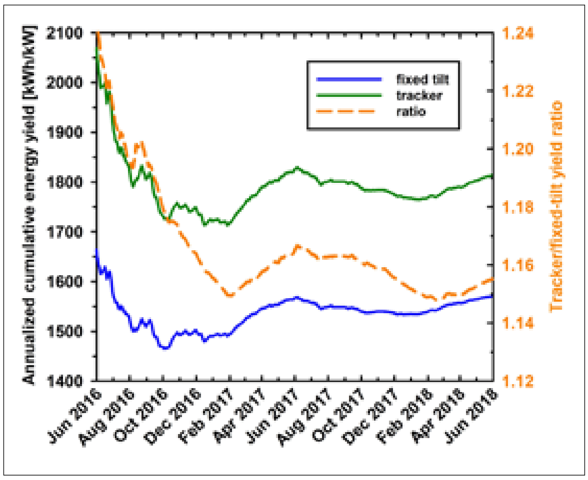

Figure 4. Comparison of the DC energy yield. The tracker yield peaks in May, just before the monsoon. The ratio is currently 1.16

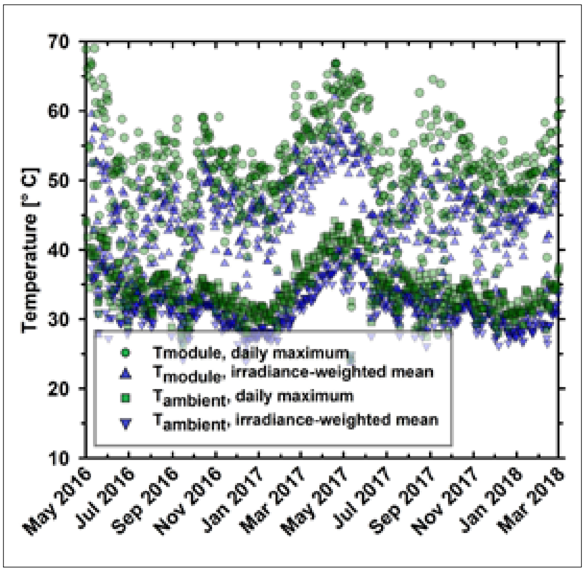

Figure 5. Daily module and ambient temperatures: maxima and irradiance-weighted means

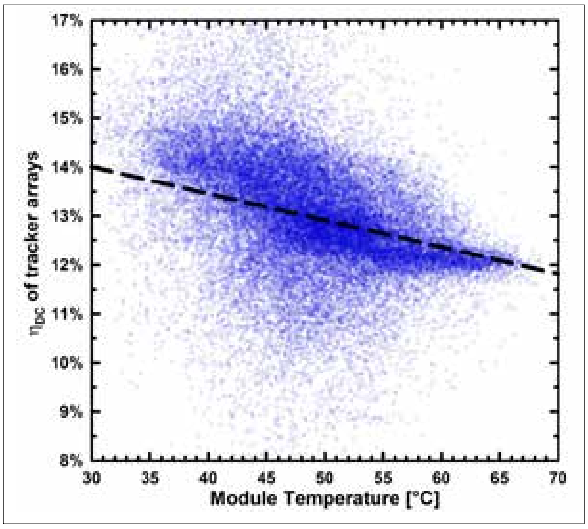

Figure 6. Array DC efficiency as a function of temperature (five-minute intervals, E>400W/m²). The line illustrates the power temperature coefficient of -0.41%/°C specified for these modules [6]

temperature. A lumped de-rate factor of 12% was applied to account for various losses for arrays in field operation. Typical component losses (and representative values) include: light-induced degradation (2-5%, in year one), annual degradation (<1%), soiling (2-4%), shading (2-8%), module-level (1%) and string-level (<1%) mismatch, and ohmic cabling losses (1-2%).

The "annualised" cumulative energy yield shown in Figure 4 is obtained by dividing the cumulative generation by the rated power and days in operation. Initially, this energy yield is strongly season-dependent, but, as the days in operation accumulate, it approaches its long-term value. As might be expected, energy yield for both fixed-tilt and tracker arrays is greatest during the months around the summer solstice (season 2), though monsoon cloud cover contributes to the decline beginning in early (rather than late) June.

The annualised cumulative energy yield stands at 1,810kWh/kW and 1,570kWh/kW for the tracker and fixed-tilt arrays, respectively. The ratio of tracker to fixed-tilt energy yield has peaked just below 1.17 and now approaches 1.16. For prospective sites, this ratio can help determine the net benefit of tracking, along with other local factors such as differences in latitude, racking cost, O&M costs and the availability of time-of-use electricity rates or pricing for grid support.

With a grid capacity of 340GW [2], India's efforts to expand and modernise the grid are being coupled with a push to over 175GW of renewables capacity, including 100GW of solar, by 2022 [3]. While the nation's energy deficit has been below 5% since 2013, and a surplus is forecast for 2018 [4], a remarkable 5GW of diesel backup power is still being added annually to cope with grid instability and occasional outages [5].

Where grid instability remains a significant issue, the enhanced ability of tracker arrays to provide ancillary services will become an asset. While trackers are usually operated to deliver maximum power, tilting trackers away from their maximum power point would provide one means for additional frequency control, or even the renewables equivalent of "spinning reserves" [7].

Temperature

The ambient temperatures at the site are compared against module temperatures in Figure 5. Module temperature is measured using thermocouples attached to the back of a module mounted on a tracker. Though the temperature of a fixed-tilt module is not monitored at this site, temperatures for the fixed-tilt-mounted modules are likely to remain at or below the values for the tracker modules.

For evaluating the effect of temperature on energy generation, it is useful to calculate temperature as weighted by the irradiance. Hourly means of one-minute data were weighted by the mean irradiance over the same period to determine the daily mean values shown in Figure 5. To date, the mean, irradiance-weighted ambient and module temperatures are 32°C and 47°C, respectively.

The difference between the module temperature as measured on a backsheet and the cell temperature inside the module is sensitive to the sensor type, the thermocouple mounting method, and the ambient temperature [8]. Applying the linear regressions for sensors 1-3

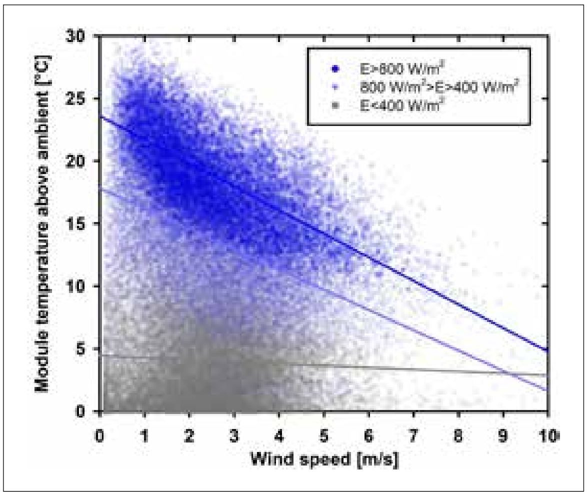

Figure 7. Impact of wind speed on (tracker) module temperature for three irradiance levels (five-minute mean values)

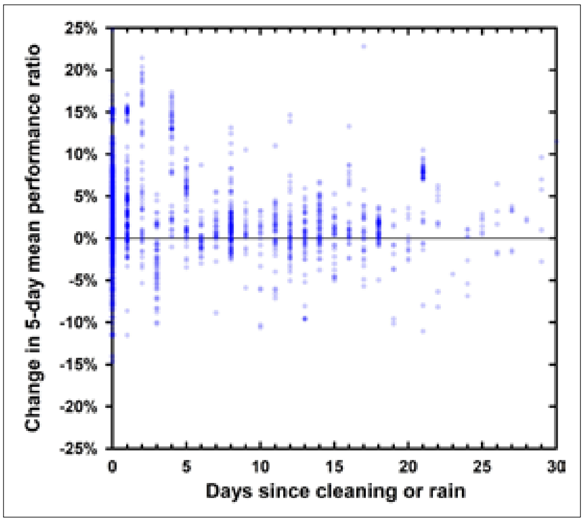

Figure 8. Relative change in DC performance ratio before and after cleaning and rain events, using a five-day mean

obtained in [8], the mean, irradiance-weighted cell temperature is 50° C (18° C above ambient). For a power temperature coefficient of -0.41%/°C [6], this corresponds to a power de-rate of 10% relative to standard test conditions (25°C cell temperature). The impact of module temperature on array performance is evident in Figure 6.

A weather station at the site monitors wind speed (but not direction). The cooling effect of wind speed on the tracker module temperature is illustrated in Figure 7. The increase in module temperature above ambient is greatest at high irradiances and the cooling effect of wind is correspondingly most pronounced. For irradiance conditions above 800 W/m2, the mean, irradiance-weighted, module temperature above ambient is 19°C, suggesting a cell temperature above ambient of 22°C. The linear regression line for E>800W/m2 can be used to calculate the module temperature for different wind conditions: at the standard wind speed of 1m/s, the expected module temperature above ambient would be 3°C higher. This difference due to the local wind conditions corresponds to a power difference of more than 1%, enough to suggest incorporating wind studies as a part of site selection and predictive performance modelling.

Soiling

The same wind that cools the modules may also exacerbate soiling. Plant performance is maintained via regular (staggered) cleaning of the arrays in each inverter block. As the resulting soiling losses are relatively low, extracting an accurate, plant-wide soiling loss rate from the performance ratio data is challenging. To assess the impact of soiling, five-day means of the daily performance ratios for each inverter block were compared before and after a cleaning event (Figure 8). A linear regression to the data with more than five days of soiling yields a soiling loss rate of 0.17% per day.

Conclusion

Quantification of the cost-benefit trades between single-axis tracker and fixed-tilt arrays is ongoing. After two years of operation, the difference in cumulative energy yields is around 1.16. While providing insight into the effects of temperature, wind speed and soiling, plants like this one, which injects over 36GWh into the grid each year, help to electrify the country and continue to chip away at India's dependence on fossil fuels. ■

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