SOLAR PV CAROUSEL TRACKERS FOR BUILDING FLAT ROOFTOPS: THREE CASE STUDIES

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ABSTRACT

Herein, a SunTrack Carousel tracker is described for mounting on residential or commercial building flat rooftops in order to produce more kWh per kW relative to fixed PV modules. The JX Crystals (JXC) fixed-tilt / azimuth carousel is a low profile tracker designed to distribute weight evenly over a large area and for low wind resistance on the roof. Multiple JXC SunTrack Carousels have now been in operation for up to 2 years at various locations in the USA. This paper describes the performance of JXC SunTrack Carousels at three different locations. Data presented herein shows that Carousel performance is consistent with RETScreen model predictions for these three sites. The RETScreen Solar model predicts that a single axis azimuth tracker will produce between 20% and 40% more kWh per solar module peak kW when compared with solar modules mounted in a fixed position without tracking.

1. INTRODUCTION

It is now clear that solar PV trackers are preferred for large remote solar PV utility fields producing peak power. However, electricity still needs to be transmitted to customer sites. Of the potential markets for PV, residential and commercial customers also represent an excellent opportunity. Residential and commercial customers presently pay retail prices for electricity rather than wholesale prices and they need electricity during the day when the sun is shining. There is an opportunity to reduce the cost of solar electricity for residential and commercial systems when trackers are mounting on building flat rooftops near the point of use.

However, for building flat rooftops, the design constraints are different. Solar trackers are needed that are sized to fit on the roof with no roof penetration and with low profiles for low wind resistance. The JX Crystals (JXC) fixed-tilt / azimuth carousel is a low profile tracker designed to distribute weight evenly over a large area and for low wind resistance on the roof [1]. As shown in figure 1, it is designed as a compact pre fabricated unit where the module-support arms fold down for easy shipping. When these arms are folded down, the carousel is only 8" tall. Without mounted modules, it is slightly less than 8 ft wide and slightly less than 10 ft long so that multiple carousels can be stacked and easily shipped on a flat bed truck. A shipping and installation sequence is shown in figure 2.

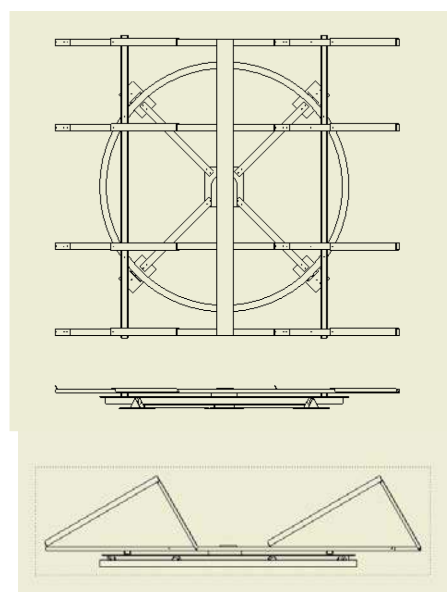
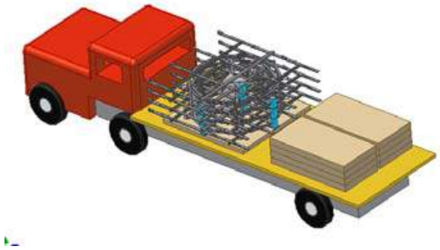


Fig. 1: The drawing above is a top down view of a JXC Carousel Tracker without the PV modules. The middle drawing is an edge view with the module support arms folded down and the bottom drawing shows the carousel after the module support arms are raised and the PV modules are mounted.



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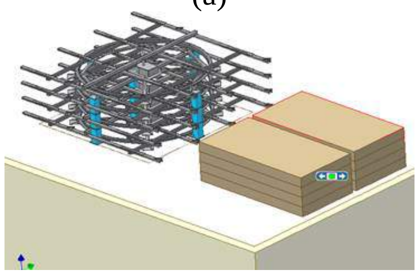

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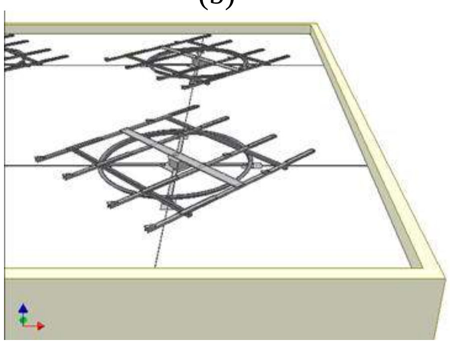

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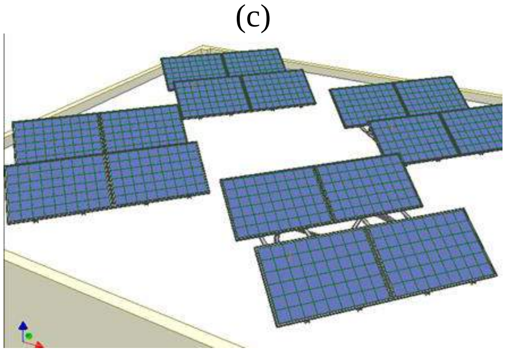


(d)

Figure 2: Carousel shipping and installation sequence.
(a) Carousel stack ships prefabricated on a flat bed truck.
(b) Hoisted to the roof.
(c) Deployed on roof.
(d) Modules mounted and operational.

JX Crystals has now installed multiple SunTrack Carousels on building flat rooftops in several locations around the USA. This paper describes three of these systems and presents an analysis of their performances.

2. <u>SUNTRACK CAROUSEL INSTALLATIONS</u>

Figures 3, 4 and 5 show three representative JXC SunTrack Carousel installations. Figure 3 shows one of the first installations in eastern Washington. Two Carousels are shown with each equipped with Sharp 208 W modules.

Figure 3: The two JXC SunTrack Carousels shown here were installed in Eastern WA in October of 2007.

Figure 4 shows four more recently installed JXC SunTrack Carousel operating on a home rooftop in Tucson AZ. Installation occurred in late September of 2009. Each of these carousels is equipped with two rows of three 195 W Sanyo modules. The 4.68 kW DC peak electrical power output from this carousel array is converted to AC with a Fronius inverter.

Figure 4: Four JX Crystals Inc SunTrack Carousels on rooftop in Tucson AZ (4.68 kW). Six Sanyo modules are mounted on each carousel in 2 rows with 3 modules per row.

Figure 5 also shows a JXC SunTrack Carousel installed on a church rooftop in San Diego in April of 2009.

This carousel is equipped with two rows of three 200 W Sanyo modules with 6 Enphase microinverters reading the outputs with one for each of the 6 modules.

Figure 5: Two views of a 1.2 kW (peak DC) JXC SunTrack Carousel mounted on a church rooftop in San Diego CA.

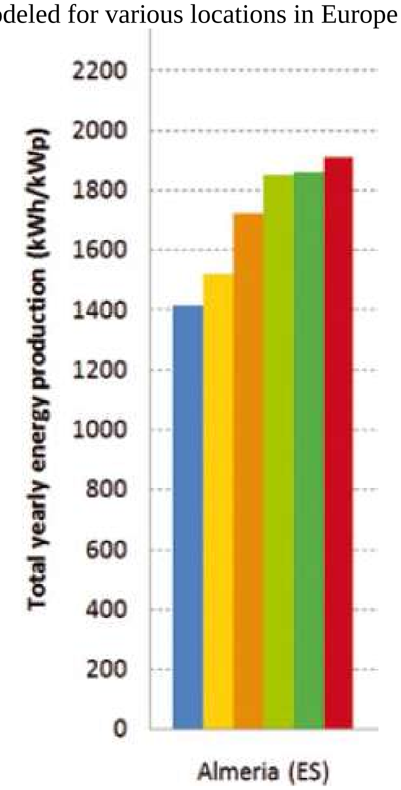
As figures 3, 4, and 5 suggest, carousels can be equipped with alternative solar module sizes from a variety of vendors. Table 1 lists some possible choices.

Table 1: Various module options are listed for mounting on the JXC SunTrack Carousel with the resultant carousel STC power ratings.

Module Type	Module Dimensions	Module Configuration	Carousel STC Power Rating
Sharp 235 W NU-U235F1	39.1"x64.6"x1.8' 994x1640x46mm	2 rows with 2 modules per row	0.94 kW
Sharp 176 W ND-176UC1	39.1"x52.3"x2.3" 994x1328x57.5mm	2 rows with 3 modules per row	1.06 kW
Sanyo 200 W HIP-200BA19	34.6"x51.9"x1.8" 880x1319x46mm	2 rows with 3 modules per row	1.2 kW

3. SUNTRACK CAROUSEL PERFORMANCE

The JXC carousel is a single axis azimuth tracker with the modules mounted at a fixed 30° tilt. The goal is to measure its performance and to compare that performance with model predictions. However, various types of single axis trackers are possible as can be seen in figure 6 and as recently modeled for various locations in Europe [2].



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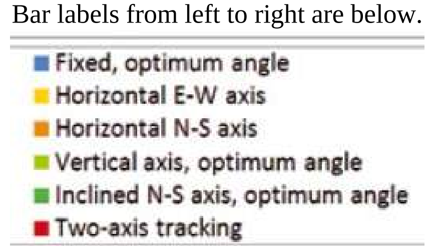

Figure 6: Tracking the sun is beneficial but various tracker types are possible [2].

Referring to figure 6, the carousel tracker is referred to as a vertical axis tracker with modules mounted at an optimal tilt angle. From this figure, for Almeria in Spain, the azimuth tracker should produce 1850 annual kWh per kWp as compared to fixed tilt modules producing 1400 annual kWh per kWp for an improvement of 1850/1400=1.32. However, this is based on modeling rather than actual data.

Various solar models are available for predicting the performance of solar PV modules at various locations and in various configurations.

There are 2 NREL reference sites that provide solar model predictions [3, 4] for locations in the US. The first [3] is the "Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors" and the second [4] is the "Solar Advisor Model or SAM". However, neither of these models include single axis azimuth trackers. They only include Horizontal N-S axis or Inclined N-S axis at optimal angle. RETScreen [5] from Canada is the only available solar modeling program that allows for azimuth tracking.

As noted, the goal here is to compare performance with model predictions. This is done for the Eastern WA carousel data set in figure 8. Model 1 in this figure is from RETScreen with azimuth tracking and Model 2 is from SAM for the Horizontal N-S axis case. Agreement with the performance data is pretty good for the summer months but lower for the winter months.

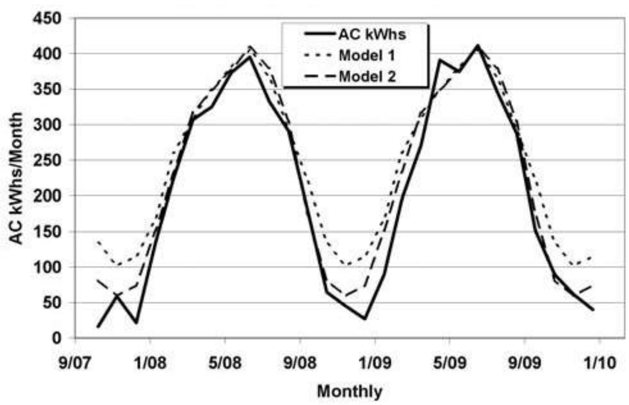

Figure 8: Carousel AC energy output is compared with model predictions for a 27 month period for the carousel in operation in Eastern WA.

Figure 9 shows the reason for the lower than predicted performance. This figure also shows a modification in the carousel design that corrects this winter performance problem.

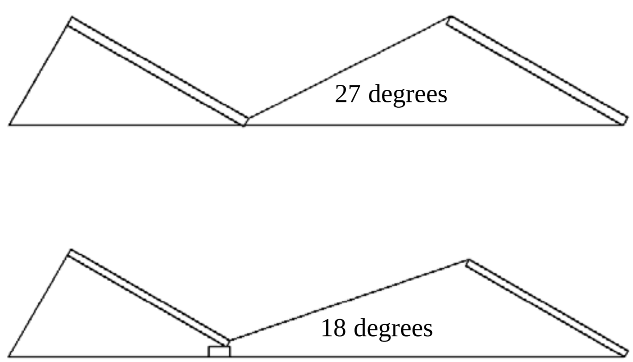

Figure 9: The front row of modules can shade the back row of modules in northern latitudes but this problem can be reduced by elevating the back row slightly.

As shown in figure 9, our early carousel design was susceptible to module back row shading by the front row for northern latitudes in the winter time when the sun angle above the horizon is low. So as a result, we then modified the carousel design by elevating the back row slightly. The angle at which the front row begins to shade the back row was thus reduced from 27^o to 18^o. The carousels deployed subsequently in San Diego and Tucson used the newer design.

The next question is: How do the carousel performances in San Diego and Tucson compare with RETScreen predictions?

Table 2 shows RETScreen predictions for various module configurations at various locations around the US. This table is most interesting because it shows that azimuth tracking is universally beneficial even in cities with lower solar resources like Seattle.

Table 2: RETScreen DC electric energy production in annual kWh per kWp and kWh/day per kWp for various cities in the US and for various module mounting configurations (Fixed Lat= tilt at local latitude).

	Tucson AZ	San Diego CA	Los Angeles CA	Yakima WA	Seattle WA
Annual kWh/kW Fixed 0^o	1929	1742	1721	1454	1159
kWh/day per kWp Fixed 0^o	5.28	4.77	4.71	3.98	3.17
Annual kWh/kW Fixed Lat	2114	1895	1871	1668	1282
kWh/day per kWp Fixed Lat	5.79	5.19	5.12	4.57	3.51
Annual kWh/kW Az 30^o	2613	2296	2273	2046	1534
kWh/day per kWp Az 30^o	7.15	6.29	6.22	5.6	4.2
Az 30 / Fixed 0^o	1.35	1.32	1.32	1.41	1.32
Az 30 / Fixed Lat	1.24	1.21	1.21	1.23	1.20

The next question is: How does the performance data from San Diego compare with predictions? Table 3 summarizes the performance data for the 10 months of operation for the carousel in San Diego and compares this data with RETScreen model predictions. Fortunately, this system provided data for both font row and back row modules in the winter and the summer. This table also provides the ratio of outputs for the front row to back row.

Table 3 allows us to make two observations. First, averaging the daily output over the front and back rows and over the ten months gives a daily output in AC kWh/day per kWp of 6.03 which is slightly higher than the RETScreen prediction of 5.86.

The second observation from table 3 is that the back row shading problem has been resolved. The average impact on the backrow by shading is 0.95.

Table 3: Performance data in AC kWh/day per kWp for the 10 months of operation for the carousel in San Diego in comparison with RETScreen model predictions.

Month	RetScreen	Front Row Ave	Back Row Ave	Back/Front Ratio
APR 09	6.45	6.9	6.79	0.98
May 09	6.63	5.74	5.69	0.99
JUN 09	6.5	7.6	7.57	0.99
JUL 09	7.28	7.79	7.67	0.99
AUG 09	7.08	7.32	7.12	0.97
SEP 09	5.88	6.23	5.93	0.95
OCT 09	5.53	6.0	5.53	0.92
NOV 09	4.6	4.42	3.98	0.90
DEC 09	4.28	4.43	4.03	0.91
JAN 10	4.4	5.13	4.82	0.94
10 Month Average	5.86	6.16	5.91	0.95

Finally, the Tucson installation is the most recent installation. It was installed in late September of 2009 but computer data did not become available until February of 2010. Figures 10, 11, and 12 show representative data output for February of 2010.

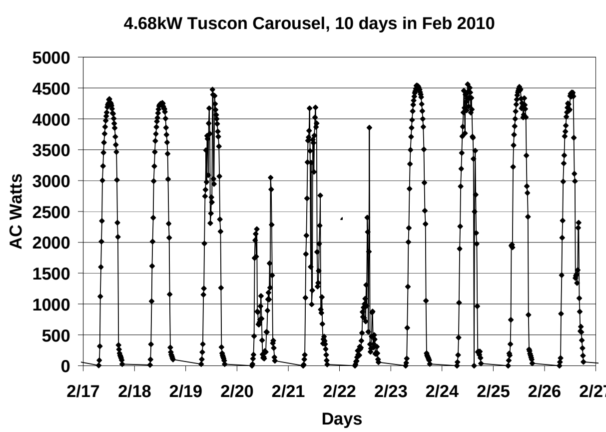

Figure 10: AC Watts from 4.68 kWp (DC) Tucson carousel installation .

While there is no computer data for this Tucson installation for the months of October of 2009 to January of 2010, the Fronius inverter did report a cumulative output for this system of 3.81 MWh. This is reasonably close to the RETScreen cumulative prediction for this Tucson carousel system of 3.38 MWh.

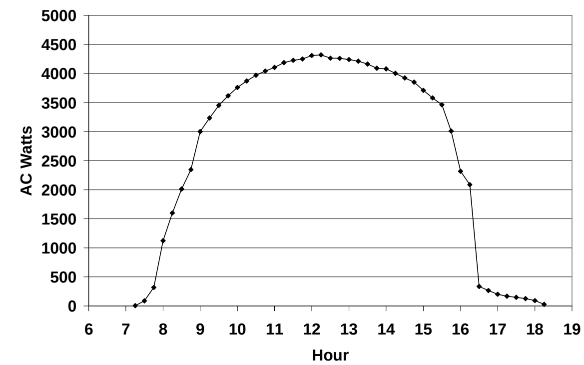

Figure 11: AC Watts from 4.68 kWp (DC) Tucson carousel installation during Feb 17, 2010.

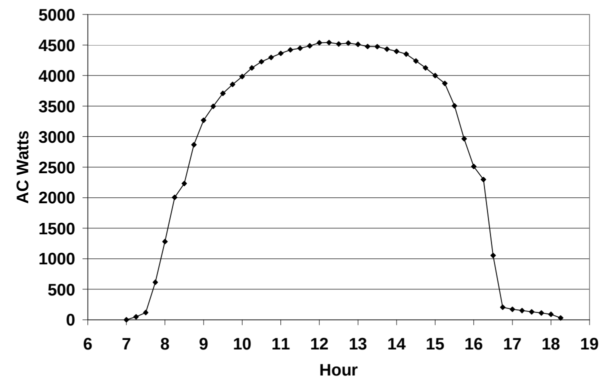

Figure 12: AC Watts from 4.68 kWp (DC) Tucson carousel installation during Feb 23, 2010.

4. BENEFIT VERSUS COST ANALYSIS

The economic viability of solar trackers is still often debated. However, there is now enough data to prove their economic benefit for the utility field case as shown in table 4 [6]. The numbers listed in this table are specifically for the baseline c-Si module case.

Table 4: Cost to benefit analysis.

Metric	Case 1: Historical	Case 2: Current	Case 3: Future
PV Module Cost	$4 per Watt	$2 per Watt	$1.5 per Watt
PV System Cost	$6.5 per W	$4.5 per W	$3.5 per W
Efficiency	12%	16%	20%
Fixed rack (FR) cost	$0.45 per W	$0.40 per W	$0.25 per W
Single-Axis (S/A) cost	$0.75 per W	$0.55 per W	$0.35 per W
S/A – FR	$0.30 per W	$0.15 per W	$0.10 per W
S/A cost penalty	(4.6%)	(3.3%)	(2.9%)
S/A energy gain	30%	30%	30%

A similar cost to benefit analysis can be done for the rooftop carousel tracker. Tracking for commercial building rooftops is newer. Several questions are often asked. In the following, some of these questions are listed and answered specifically for the 1.2 kW carousel tracker.

Question #1: How much energy is consumed for tracking and how does that compare with the energy produced?

Answer #1: A solar tracker rotates one-half revolution during the day. It does this in very small steps. It returns to the starting point over night. Specifically for the rooftop carousel, the energy required per day is 6 Wh and the energy produced per day is 6 kWh. So the energy required is 0.1% relative to the energy produced.

Question #2: What is the cost per W for a solar rooftop tracker?

Answer #2: The answer to this question is a function of production volume and manufacturing set-up. Production volume today for the carousels is small and the manufacturing is done in a small prototype shop. However, a cost estimate in high volume production can be made given its weight. The weight of the carousel without modules is about 200 pounds. By analogy, a Kenmore washer weighs about 250 pounds. A washing machine also has a drive motor and a controller just like a solar tracker and it can be purchased and installed for about $400. This installed price for a 1.2 kW rooftop tracker translates to $0.33 per W.

Question #3: How much does the drive system cost?

Answer #3: Again by analogy, one can purchase the drive with control for a satellite dish for about $85. For a solar tracker producing 1.2 kW, this cost will translate to about $0.09 per W.

Question #4: What about reliability and operation and maintenance cost?

Answer #4: Nearly every home today has appliances with motors. Examples are washing machines and refrigerators. These systems are very reliable and there is an infrastructure for O&M. Furthermore, solar trackers now have over a decade of operating experience. Note that solar trackers only turn one revolution per day. This equates to 7300 revolutions in 20 years. By analogy with a simple wrist watch, this equates to the number of revolutions the second hand on a watch will make in 121.66 hours or 5 days.

5. CONCLUSIONS

For larger PV systems today, the question is no longer whether or not to track the sun. The relevant question now is how to track the sun. Several tracker geometries and tracker types have been developed and described here. It is now time to scale up production in order to reduce costs. Tracking yields a lower cost for solar electricity and a faster payback time for customers.

6. R EFERENCES

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