1-YEAR PERFORMANCE OF CRYSTALLINE TECHNOLOGIES ON DIFFERENT TRACKING SYSTEMS

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ABSTRACT: Since August 2010 EURAC has been monitoring a 724 kWp multi-technology test field at the Airport of Bolzano Dolomiti (ABD) in the Italian Alps. The modules are mounted on fixed-tilt racks (30°) as well as on a single- and a dual-axis tracker. This work presents the results of one-year comparison between different crystalline PV technologies based on monocrystalline silicon (mc-Si), polycrystalline silicon (pc-Si) and heterojunction with intrinsic thin-layer (HIT), mounted on single- and dual-axis trackers. The performances are also compared to modules on 30°-tilted fixed racks, covering the time span between July 2011 and June 2012 (second year of plant operation).
The comparison is carried out in terms of daily profiles of normalized power output, average yearly module temperature and pseudo performance ratio.
The results show major advantages in using a dual-axis tracker especially during winter, and a better performance of the HIT modules with respect to the other technologies on almost all the mounting systems.
Keywords: tracking, c-Si, pseudo performance ratio

1 INTRODUCTION

Sun-tracking systems are widely spread due to their capacity to optimize the performance of a PV plant. Their use implies higher costs of installation and maintenance compared to fixed systems, but assures a higher energy output during the whole year [1]. There are many papers which estimate the performance of specific tracker systems using monitored data [2-4], but very few of them consider a comparison of the performance of different technologies installed on different tracking solutions.

This paper presents the results of 1-year monitoring activity of three different crystalline technologies: monocrystalline silicon (mc-Si), polycrystalline silicon (pc-Si) and heterojunction with intrinsic thin-layer (HIT). They are installed on two different tracking systems with a single- and a dual-axis, respectively.

The data are elaborated in terms of average module temperature and performance ratio based on the global horizontal irradiation. The results are compared to the behavior of modules on a fixed mounting system (30°-tilted).

2 EXPERIMENTAL SETUP

The PV test field at the Airport of Bolzano Dolomiti (ABD) owned by ABD and developed with a co-financing of the European Regional Development Fund (ERDF), is divided into two main parts: a 662 kW commercial installation with 8538 CdTe modules, and a 62 kW experimental installation with 24 different types of modules, divided into 39 arrays ranging between 1 and 2 kW each [5], and positioned as follows:

- 32 arrays on fixed supports, with an orientation of 8.5° West of South and a tilt angle of 30°
- 3 arrays on a single-axis active tracker, with an inclination of 30° and a rotation around the vertical axis of ± 45° East-West
- 4 arrays on a dual-axis active tracker with an inclination ranging between 15° and 90°, and an East-West rotation capability of 360°.

The two tracking systems are programmed to be aligned with the brightest point in the sky. In addition, the dual-axis tracker is equipped with a safety sensor to prevent the system integrity against high loads of wind.

Each array is connected to a string inverter that measures the electrical performance with a frequency of 15 minutes. For the purpose of this work, just the electrical parameters on the DC side are taken into consideration, thus excluding the effects of the inverter conversion efficiency and system losses in general.

The PV test facility is equipped with a meteo station, with sensors for the measurement of wind speed and ambient temperature, a pyranometer mounted on the horizontal plane and three c-Si reference cells mounted respectively on a 30°-tilted support, and in-plane with the trackers. Since the reference cells showed connection problems during part of the monitoring period, their datasets are incomplete and were not used in this work. The performance of the investigated technologies is therefore evaluated using the irradiance data measured with the pyranometer as reference, which was calibrated prior to outdoor exposure by an ISO 17025 accredited laboratory.

Pt100 sensors are installed on the back of each array, in order to monitor the module working temperature.

The main characteristics of the arrays are summarized in table 1.

Table 1 Characteristics of the monitored modules and arrays on the different mounting systems.

Type	Number of modules	Array nominal power (W_p)
mc-Si	4	1200
pc-Si	20	4200
HIT	18	3870
mc-Si (1-ax)	4	1200
pc-Si (1-ax)	8	1680
HIT (1-ax)	5	1075
mc-Si (2-ax)	5	1500
pc-Si (2-ax)	8	1680
HIT (2-ax)	8	1720

3 RESULTS AND DISCUSSION

3.1 Normalized output power profiles

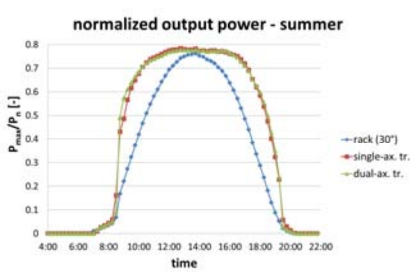
Figures 1a and 1b show the daily profiles of the instant output power P_{max} normalized to the array nominal power, P_n. The profiles refer to two clear sky days, respectively in summer and winter, for the pc-Si technology.

Since the array-generated power is dependent on the irradiance, *G*, the shape of the normalized power profiles is strictly related to the trend of the corresponding in-plane irradiance profiles [6]. Tracker systems are able to be aligned continuously with the sun, thus resulting in more flat profiles. On the other hand, the normalized output power of the fixed plane has a Gaussian shape. The curves measured at ABD always show a missing tail corresponding to sunrise and sunset, when shading is caused by mountains both at the east and west of the multi-technology installation which is more evident during winter. The single-axis tracker clearly shows an unexpected shape during the winter day, since its peak falls earlier than the sun peak. The same trend is registered during the other clear sky days of the winter season and it definitely seems to be related to a miss-tracking problem.

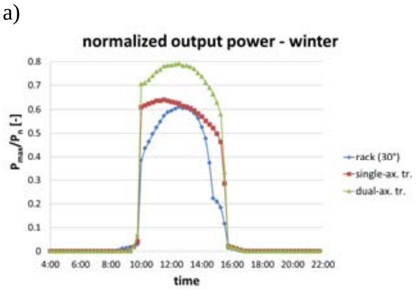
If we focus on the peak values we see that the normalized power of the dual-axis tracker is similar during summer and winter. The higher irradiance received by the modules during summer compared to winter (which was measured being around 1000 and 900 W/m^2 on clear sky days respectively) is compensated by the lower efficiency in energy production due to higher module temperatures (25 ÷ 30 °C difference between the two seasons at sun peak). The single axis tracker is able to move from east to west maintaining a fixed tilt of 30°, which is close to the optimal tilt angle of 35° for Bolzano with the consequence that

a) during summer, when the sun elevation forms small angles of incidence with the modules, the normalized output power is very close to that of dual-axis tracker,

b) during winter, when the sun elevation is lower, the peak value of output power results closer to that of the fixed rack.



a)



b)

Figure 1: Normalized output power profiles measured on fixed rack and on single- and dual-axis trackers during a summer (a) and a winter day (b), under clear sky conditions for the pc-Si technology.

Figure 2 represents the percentage of energy output gain achieved with the double-axis tracker with respect to the single-axis tracker, for the whole monitoring period and for the pc-Si technology. The data are filtered in order to exclude periods with trackers´ malfunctions. It confirms that the advantages of a dual-axis tracking system are more evident during winter months at the ABD installation, and reach a peak of 20% in December. The average yearly value is 5%.

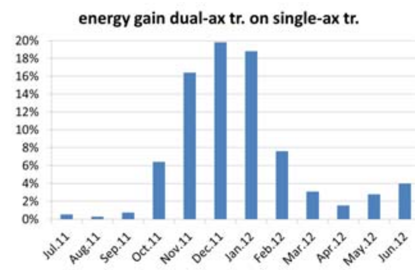


Figure 2: Gain of energy output for the dual-axis tracker, in percentage, with respect to single-axis tracker for the pc-Si technology.

3.2 Temperature measurements

The module temperature is strictly dependent on the irradiance level [6]. Table 2 shows the average yearly temperature of the modules during operating time. As expected, higher temperatures are reached on the modules installed on the trackers, while the rack shows 2.5 °C lower temperatures on average.

The modules on the trackers show in general the same temperature, while this differs more evidently on the modules mounted on the fixed rack. This could be due to the not uniform ventilation on the three arrays on the rack, which are positioned in different parts of the multi-technology plant (surrounded by other arrays rather than free at one or more sides).

Table 2 Average yearly temperature of the monitored modules.

	Average yearly module temperature (°C)		
Type	fixed rack	single-axis tracker	double-axis tracker
mc-Si	23.9	27.2	27.6
pc-Si	26.1	27.2	27.3
HIT	24.7	26.5	27.2

3.3 Pseudo Performance Ratio

The performance ratio is defined by the international standard IEC 61724 [7] as the final energy yield of a PV system, Y_f, divided by the reference yield Y_r, the latter being the ratio of the in-plane global insolation *H* and the irradiance under STC (G = 1 kW/m^2). Since a complete dataset from in-plane mounted reference cells is not available as stated in section 2, a pseudo performance ratio is calculated in this work that uses the global horizontal irradiance in place of the global in-plane irradiance. The data are previously filtered for the wind speed: this is in fact a limiting factor for the correct evaluation of the energy yield of the dual-axis tracker, which is equipped with a wind sensor that brings the system to the safety position (horizontal plane) when a wind speed threshold is exceeded. Furthermore, the values of pseudo PR are calculated considering the same operation time. This is done in order to better compare technologies mounted on different installation types rather than to compare the installation types.

Figure 2 shows the pseudo performance ratio of the three monitored technologies, for every different mounting system. All the monitored technologies show in general the typical trend of silicon-based crystalline modules, with lower values during warm months due to temperature effects, and higher during cold months [8].

If we compare the performance of the different technologies on one mounting system, it has to be pointed out that the values of pseudo PR of the single-axis tracker cannot be taken into consideration. Even though these values fall in general between those of fixed rack and dual-axis tracker, the performances of the three crystalline technologies do not show the same trends as in the other mounting systems. This difference is not justified by the tolerance of the modules´ nominal power given by the manufacturers (+5% ÷ -3% for mc-Si, +5 ÷ -5% for pc-Si, +10% ÷ -5% for HIT), and it could be related to inverter Maximum Power Point miss-tracking (especially for the pc-Si and HIT modules). This aspect definitely needs further and more detailed investigations before such a hypothesis is confirmed.

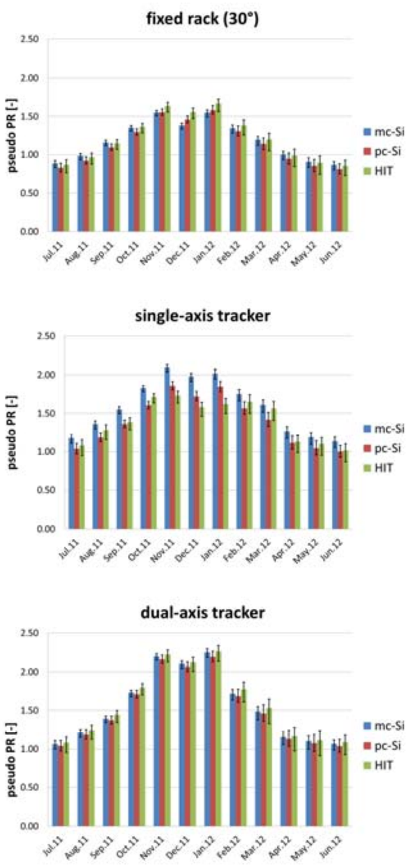


Figure 3: Pseudo Performance Ratio and tolerance bars of the monitored technologies for each mounting system, calculated with respect to the global irradiance on the horizontal plane.

Comparing the pseudo PR values of the modules mounted on the fixed rack system and on the dual-axis tracker, the latter clearly shows a more marked peak during winter months. As already shown in section 3.1, this can be explained by the better efficiency in tracking the solar radiation with the two axis systems during months when the sun elevation is low and a module fixed-tilted angle of 30° does not allow to achieve values of angle of incidence close to zero. Furthermore, the two figures show in general a better performance of HIT technology, followed by mc-Si and pc-Si. The difference between the values of pseudo PR of HIT and pc-Si is on average 4%, that increases up to 7% on the fixed rack during winter months.

4 CONCLUSIONS

This paper presented the results of a one-year monitoring of three different crystalline technologies (mc-Si, pc-Si and HIT) mounted on a fixed rack (30°-tilted), on single- and dual-axis trackers at ABD test facility in Bolzano, Italy.

The results showed that the HIT technology performs better on the fixed rack and on the dual-axis tracker, followed by mc-Si and pc-Si. The difference between the performance of HIT and pc-Si is on average 4%, and it increases up to 7% during winter on the rack system due to the higher efficiency of this technology under high angles of incidence.

The three monitored technologies mounted on the single-axis tracker showed unexpected differences in the values of pseudo PR, which are not explainable with a miss-tracking of the sun position identified on this mounting system. A possible cause has been identified in the inverter miss-tracking of Maximum Power Point, but it definitely needs further and deeper investigations.

Finally, it can be concluded that the major advantages in the tracking are assured by the dual-axis tracker during winter months when the angle of incidence of the sun is not optimal for modules with a fixed 30° tilt. The gain of energy output performed by the dual-axis tracker, with respect to the single-axis tracker, reaches a maximum of 20% in December, with an average yearly value of 5%.

4 ACKNOWLEDGMENTS

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