Solar Engineering
Decker & Mack GmbH

www.solar-engineering.de

Vahrenwalder Straße 7
D 30165 Hannover
Telefon: +49 -(0)- 511 9357 330
FAX: +49 -(0)- 511 9357 339
mail: info@solar-engineering.de

Yield Study s:wheel

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Author :

Dr. Michael Mack

Solar Engineering Decker & Mack GmbH

Geschäftsführer/ management:
Burchard Decker, Michael Mack

D-U-N-S-Nr.: 329 035 237
Handelsregister/ register of companies:
Amtsgericht Hannover HRB 58103
USt.-IdNr./ VAT-ID: DE 812 785 404

Summary

Two PV module configurations are compared at the Spanish location Almansa/ Alicante. The first configuration is a s:wheel set up (azimutal tracking including backtracking) with 30 degrees inclination and a specific row distance, the other one a fixed row installation with the same inclination and the same row distance. The yield comparison is made for the module DC output.
The comparison uses specific meteo data of the location and state-of-the art system specific yield calculations.
There results a solid 25 % advantage for the s:wheel configuration. The annual module DC output amounts to 1881 kWh/m²a for the s:wheel configuration and to 1501 kWh/m²a for the fixed row installation.
This result depends on the diffuse and global irradiation sums of the location and the chosen row set up. It is therefore valid only for the specific conditions as described.

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Dr. Michael Mack

SOLAR ENGINEERING

Solar Engineering Decker & Mack GmbH
Vahrenwalder Straße 7 · D 30165 Hannover

D-U-N-S-Nr. 329 035 237

www.solar-engineering.de

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1 Task

RWenergy requires a yield comparison between two mounting configurations of PV modules at the Spanish location of Almansa / Alicante. The first configuration is a s:wheel set up (azimutal tracking including backtracking) with 30 degrees inclination and a specific row distance, the other one a fixed row installation, facing South, with the same inclination and the same row distance. The yield comparison is to be made for the module DC output.

2 Mounting configurations

2.1 s:wheel

The s:wheel is a near surface mounting system which performs azimutal tracking. Single layer modules in portrait position with fixed inclination are mounted in rows with fixed distance. This PV array is mounted to a horizontal large diameter wheel which provides the circular azimutal movement of the whole array.

s:wheel set up present case		
total number of modules	200	
number of rows	9	
Inclination	30	degrees
free space row distance	1564	mm
module length inclined	1589	mm
shadow generating vertical height of module	794,5	Mm
resulting shadow angle	26,93	degrees
number of modules per row		
row 1 & 9	*11*	
row 2 & 8	*19*	
row 3, 4, 5, 6, 7	*28*	

table 1 : s:wheel configuration data

In principle, azimutal tracking is applied, i.e. the azimutal orientation of the module rows equals the sun´s azimut. To avoid mutual shadowing of the module rows, however, so-called backtracking is applied.

fig. 1: example s-wheel installation (Barcelona/ Spain)

2.2 Backtracking

Whenever the solar height angle is below the direct aspect shadow angle of the row configuration, the modules are not oriented toward the sun´s azimut, but put at that azimutal orientation where the mutual (direct beam) shadowing of the rows is just avoided. At very low solar elevations (i.e. early in the morning and late in the evening) the “backtracked” azimutal orientation is nearly perpendicular to the sun´s azimut. With increasing solar height the module azimut is continously readjusted, i.e. the difference between the module azimut and the solar azimut decreases continously. When the solar height angle equals the shadow angle, this difference becomes zero, i.e. the module azimut equals the solar azimut. For the time where the solar height is larger than the shadow angle, pure azimutal tracking is applied.
The difference between solar azimut and azimut orientation of the modules is called backtracking angle or shift angle.
The continous adjustment of the shift angle σ is determined by the equation

As a result of the backtracking, the mutual direct beam shadowing of the module rows is completely avoided. This occurs at the expense of an increased incidence angle during the backtracking times. The increased incidence angle reduces the direct beam and circumsolar radiation components accordingly and induces raised reflection losses for those radiation components.
There remains a small difference in irradiation between a completely unshadowed module and the row set up. A completely unshadowed module experiences the complete diffuse sky radiation from an unobstructed sky. A module with the next module row in front, however, experiences an obstruction of the luminous sky as the backside of the row in front of it is dark compared with the luminous sky.

2.3 Fixed row installation

The fixed row installation is completely identical to the row installation of the s:wheel set up, i.e. it has the same inclination and the same shadow angle. An inner module experiences the same obstruction of luminous sky as the s:wheel set up. The irradiation of the fixed set up is lower than the irradiation of the azimutal tracking set up with backtracking. In addition, there is mutual shadowing of the rows according to the shadow angle.

3 Location and meteo data

The comparison is to be made for the Spanish location Almansa/ Alicante (LAT 38,845 ° N, LON –1,0284 ° W, altitude 684 m a.s.l.).
Meteo data (global and diffuse horizontal irradiation, air temperature) are taken from the data source METEONORM (MN 5.107) by direct interpolation for the geographical coordinates of the location. The outcome of the METEONORM interpolation was checked by comparison with a reading from the PVGIS European map. The difference in annual global horizontal irradiation between both readings is less than 2 %. PVGIS (H_Gh year = 1657 kWh/m²a) shows a slightly lower diffuse to global ratio (H_Dh year = 630 kWh/m²a) and slightly higher air temperatures (year average 17,7 °C). For the present comparison these differences may be safely neglected. To be consistent with the statistics of hourly meteo data the MN 5.107 data are chosen.

Almansa/ Alicante Spain			
month	**H_Gh**	**H_Dh**	**T_day_hours**
	kWh/m²	**kWh/m²**	**°C**
Jan	74	30	7,2
Feb	85	37	8,8
Mar	118	58	11,1
Apr	156	74	13,1
May	177	85	17,3
Jun	219	76	22,4
Jul	230	72	26,8
Aug	206	66	26,3
Sep	131	64	22,2
Oct	94	48	16,4
Nov	73	36	10,9
Dec	65	29	7,3
YEAR	**1625**	**674**	**16,6**

table 2: Almansa meteo averages (MN 5.107)

In essence, the chosen irradiation data for the location are long term averages based on an interpolation of the 1981 – 1990 average data of the surrounding terrestrial meteo stations as given in the European Solar Radiation Atlas (ESRA).

4 Method of Calculation

For the calculation the method PR-Fact is used which has been extensively validated against the well-known software tool PV Syst. PR-Fact is used instead due to its higher transparency for results.

Starting point of the calculations are the long term average global and diffuse horizontal irradiation at the location taken as hourly values. From these data the hourly irradiation to the PV-modules ("tracked surface irradiation" or "inclined surface irradiation") is calculated taking into account the solar position at the hour in question and the altitude of the location above sea level. The tracked / inclined surface irradiation is separated in in the different radiation components: direct beam irradiation, circumsolar irradiation, diffuse sky, diffuse ground-reflected and diffuse horizon band irradiation, according to the method of Perez et al.

In a second step, shadowing effects, reflection losses and effects of spectral variations are acounted for. This results in appropriate reduction factors for the different components of the inclined surface irradiation (factors f_0 … f_2). In this, circumsolar irradiation is treated in the same manner as direct beam irradiation.

The third step calculates the average monthly electric yield of the PV modules based on the calculation of hourly performance. This results in reduction factors for the standard test condition (STC) efficiency of the module (factors f_3 , f_4).

This module DC output is taken to compare both configurations. The yield figures are given as specific yield, i.e. independent of the actual module efficency.

For the model calculation an average PV module is chosen (module efficiency at 200 W/m² compared to 1000 W/m² ("low irradiation parameter") = 0,917, power temperature losses = – 0,46 %/ K). For the calculation of the reflection losses a mono-Si module is assumed.
The calculation is done for inner modules, i.e. modules with a complete next module row in front of it. At present, fringe effects (which will induce very small alterations only) are not accounted for.

5 Results

5.1 Module surface irradiation sums

Table 3 gives the unshadowed irradiation sums for the fixed row installation and for the s:wheel set up, i.e. azimutal tracking including backtracking as required by the s:wheel row distance. The advantage in annual irradiation amounts only to 15 %. For November to January the irradiation for the s:wheel is even lower than for the fixed row installation.

It is interesting to compare the s:wheel irradiation sum to pure unshadowed azimutal tracking (table 4). The s:wheel tracking year irradiation sum is only 5 % below the irradiation sum of pure unshadowed azimutal tracking, and even in the winter months the difference is not much larger than 10 %.

ALMANSA	**fixed rows**	**s:wheel**	
month	global irradiation G_k module surface	Global irradiation G_nk module surface	*irradiation ratio s:wheel / fix*
	kWh/m²	kWh/m²	
Jan	119,3	116,1	*0,973*
Feb	119,5	123,8	*1,036*
Mar	139,3	153,4	*1,102*
Apr	167,8	197,3	*1,176*
May	175,1	214,4	*1,225*
Jun	208,0	270,0	*1,298*
Jul	222,2	287,6	*1,294*
Aug	217,6	267,1	*1,227*
Sep	147,5	167,3	*1,134*
Oct	119,5	127,8	*1,070*
Nov	110,3	109,2	*0,989*
Dec	108,1	102,5	*0,948*
Year	**1854,2**	**2136,7**	***1,152***

table 3: unshadowed module surface irradiation sums for fixed rows and for s:wheel set up, location Almansa/ Alicante

ALMANSA	**azimutal**	**s:wheel**	
month	global irradiation G_nk module surface	global irradiation G_nk module surface	*irradiation ratio s:wheel/ azi*
Jan	130,4	116,1	*0,891*
Feb	132,9	123,8	*0,932*
Mar	160,7	153,4	*0,955*
Apr	204,3	197,3	*0,966*
May	221,9	214,4	*0,966*
Jun	279,0	270,0	*0,968*
Jul	297,9	287,6	*0,965*
Aug	276,3	267,1	*0,967*
Sep	173,4	167,3	*0,965*
Oct	134,9	127,8	*0,948*
Nov	120,8	109,2	*0,904*
Dec	115,9	102,5	*0,885*
Year	**2248,4**	**2136,7**	***0,950***

table 4: comparison between unshadowed azimutal tracking and s:wheel results of table 3 for Almansa/ Alicante

However, irradiation alone is not decisive for the yield.

5.2 System performance and electric output

If one takes into account as well the spectral losses (identical for both configurations), the reflection losses for non-zero incidence angles, the shadowing losses and the module performance one arrives at the DC output of the module. As the further losses downstream the system (mismatch losses, wiring losses, inverter and MPPT losses) are nearly identical for both configurations, the difference in module DC output (table 5) reflects the difference in final electric yield.

Due to the fact that the expenses for avoiding direct beam shadowing have already been accounted for in the s:wheel irradiation sum, the performance of the s:wheel configuration is much better than for the fixed row installation. Whereas the latter has to bear an annual average of about 6,5 % direct beam shadowing losses, these losse are set to zero by the s:wheel backtracking (fig. 2).

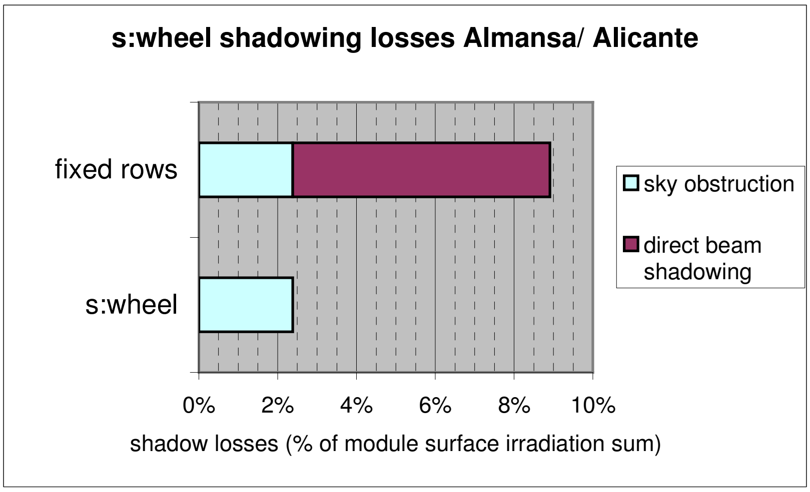

fig. 2: Shadow losses comparison. Both configurations experience about 2,4 % losses due to sky obstruction. That brings the total shadowing losses for fixed rows up to 8,9 %, whereas s:wheel experiences only the quoted 2,4 % losses due to sky obstruction.

In addition, the azimutal s:wheel tracking reduces the reflection losses to an annual value of 1,8 % which for the fixed row installation amount to an annual value of 2,6 %. The module performance – here as preliminary model calculation – is nearly identical for both configurations. The final ranking will depend on the specific module used (fig.3). All effects together lead to an improvement of the "module-DC performance ratio (DC-PR)" from 0,81 for fixed rows to 0,88 for the s:wheel configuration.

It is noteworthy that especially in the winter months the electric yield of the s:wheel is better than that of the fixed row intsallation, despite the lower irradiation impinging to the s:wheel tracked modules. This is due to the high shadowing losses (e.g. 50 % in December, 30 % in January) which appear at the chosen shadow angle in the winter months for fixed row installation.

Thus, the shadowing losses for the fixed row installation show up in the system losses (factor f_1), whereas the expenses paid for the intelligent avoidance of direct beam shadowing show up already in the s:wheel irradiation data.

Therefore, it is indispensable to use electric output data for a comparison of both configurations. Any comparison using irradiation data only is bound to fail.

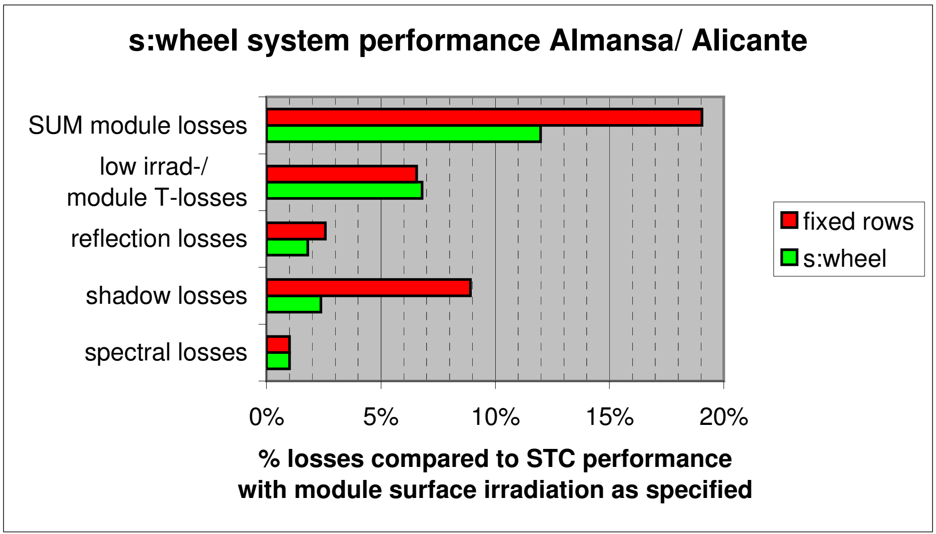

fig. 3: System performance comparison for both configurations.

Month	**spec. yield fixed rows**	**spec. yield s:wheel**	*module DC spec. yield ratio s:wheel / fix*
	kWh/kWp	kWh/kWp	
Jan	76,8	107,0	*1,393*
Feb	102,1	113,3	*1,110*
Mar	122,7	137,0	*1,116*
Apr	147,7	177,4	*1,201*
May	150,3	188,5	*1,254*
Jun	177,7	236,0	*1,328*
Jul	186,3	246,3	*1,322*
Aug	183,1	229,0	*1,251*
Sep	124,1	142,8	*1,151*
Oct	102,2	111,4	*1,090*
Nov	78,7	98,4	*1,251*
Dec	49,5	93,6	*1,892*
Year	**1501,2**	**1880,7**	*1,253*
PR DC year	**0,810**	**0,880**	-

table 5: module DC output given as specific electric yield for location Almansa/ Alicante. The PR value is the complement of the sum of module losses depicted in fig. 3.

There results a solid 25 % advantage for the s:wheel installation as compared to a row installation of the same inclination and shadow angle[1]. An at least nearly identical advantage is to be expected for the final AC yield downstream.

The results described above depend on the diffuse and global irradiation sums of the location and the chosen row set up. They are therefore valid only for the specific conditions as specified.

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[1] Even if the module DC output of an unshadowed fixed module (South, 30 deg inclination) is taken as reference (annual specific yield Almansa = 1643 kWh/m²a) there remains a DC output advantage of at least 14 % for the s:wheel installation. Therefore, at Almansa/ Alicante, any real fixed row installation with (much) wider row distances will have about 16 % to 24 % less DC output than the s:wheel configuration described here, even if the unshadowed first row is taken into account properly.