SOLAR WINGS A NEW LIGHTWEIGHT PV TRACKING SYSTEM

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ABSTRACT: Solar tracking systems increase the electricity production by about 30% relative to fixed installations. A robust design of the mechanical system requiring less material than 100kg steel per kW nominal PV module power is essential to further improve the economics of PV tracker plants. The Solar Wings approach reaches this goal by using steel cables as a mounting system for the PV modules and benefits by the long-time experience of project partner BMF using steel cables in transportation systems such as ski-lift, funicular, aerial passenger lines. Tests with the first Solar Wings prototype in Switzerland passed successfully. The first 600 kW PV plant powered by the one axis Solar Wings tracking system will put into operation in December 2008 in Southern Germany. To maximize reliability and reduce maintenance costs only one electrical three-phase asynchronous motor is used to track 100kW PV modules. A two-axis tracking Solar Wings system will be available next year. Further development targets are low optical concentration by the use of planar mirrors mounted on a parallel axis to the PV module axis. PV modules and mirrors track individually and thus an increase of the electricity production of higher than 60% relative to fixed mounted installation is expected. First results of the measured increase of performance by individual tracking of the planar mirrors and the PV modules, performed on a small scale dish model, are reported.
Keywords: Tracking, Concentrators, Reliability

1 INTRODUCTION

Today worldwide about 250 MW PV modules are operated on top of PV trackers [1]. Due to the fact that the market share of large scale system is rising and today about one quarter of the large scale PV plants are equipped with trackers, the PV tracker market is growing at a rapid pace.

It is well known that in theory 41% more sunlight is available by tracking the PV module to follow the daily course of the sun, relative to fixed installations [2]. Calculated values between 31% and 36% of the two-axis gain in the Mediterranean region, compared to fixed installations are given in Table I.

Huld showed [3] that in Northwest and Central Europe the relative gain of two-axis tracking is higher than in the south. The absolute gain of tracking however is still low at 250 kWh per kW_p in the north, were typical yearly gains in Portugal and the Mediterranean region are in the range of 400-600 kWh per kW_p.

Due to the fact that most of the gain is reached in the morning and evening period, when the sun height is low, the two-axis tracker should be placed not to close to one another to prevent cross shadowing. This results in lower yield of nominal MW PV power installed on the same square kilometer available ground space. The resulted ground coverage ratio (GCR) is up to 50% for fixed installations while one axis trackers can reach up to 35% and two-axis dish trackers only have a GCR value of 20% in the Southern Europe region [4, 6]. Two axis trackers with parallel axis show a higher GCR ratio, but a little bit lower gain in power due to the neighborhood tracker shadowing. These type of trackers applied with parallel axis can be operated by a simple tracking mechanism with higher reliability as shown later in this paper. Several trackers are on the market and prices range between €100 and €250 per square meter of PV module area with an average at 160€/m^2. This results in prices relative to Wp between 0.8 and 1.7€/Wp with an average of 1.1€/Wp [5]

Table I: Calculated solar input gain of two-axis tracking relative to a fixed installation tilted at 35° in several Southern European locations using the online PVGIS tool [3].

Site	Latitude	Gain P_{IN} [%]
Zürich, CH	47°22'	24%
Genova, It	44°24'	31%
Barcelona, Sp	41°23'	33%
Valencia, Sp	39°27'	31%
Malaga, Sp	36°43'	36%
Tunis, Tu	36°49'	33%
Nadur, Malta	36°2'	36%
El Paso *	31°30'	57%

* Ratio is given in Ref [6]

Table II: Reported PV performance gain of commercial trackers relative to fixed PV module installation (location Southern Europe)

	PV gain	Ref.
Single axis horizontal	>25%	[7]
Single axis tilted 20°	>30%	[7]
Single axis tilted, three positions	25%	[9]
Two axis tracking, parallel axis	>30%	[8]
Tow axis tracking, dish	40%	[8]
Theoretical limit two axis tracking	41%	[2]

Today's typical PV tracker on the market in average require approx. 200kg steel to track 1kWp nominal module power [5]. In the last four years the price of commodity steel climbed by the factor of 2.5 [Fig. 1]. The price of heavy steel plates will be €950 per ton in the fourth quarter of 2008 [10]. That accounts for €200 per kWp only for the commodity steel price not included the processing cost to get the intermediate steel products like the appropriate steel profile. In 2012 this value may rise to about 300€/kWp, if the weight density will stay at 200kg/kWp and thus costs of steel will be 10% of the overall PV system price, higher than inverter costs.

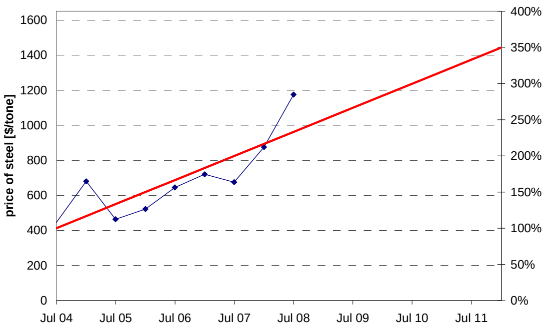

Figure 1: Price of steel, import prices CFR Dubai, cold rolled foils 1mm according to [11]; the straight line is a linear fit to the relative prices shown on the right hand scale with an increase to 350% in January 2012 relative to the value of July 2004.

2 SOLAR WINGS TRACKING SYSTEM

2.1 Basic Design and Features: One-axis tracking

Current PV tracking systems require typically 200kg of metal (steel or aluminum) to fulfill the wind load requirements in their design. The Solar Wing approach uses cables to mount the modules and thus meets wind load requirements with far less steel.

Solar Wings tracking systems take advantage of cables of several 100 meters in length to mount the solar modules several meters above ground. In standard applications like ski-lift, funicular and aerial passenger lines, cables are used as the cost-saving solution, reducing the cost of foundation at highest reliability and safety standard to the customers. As shown in Fig. 2 the beams carry the PV modules mounted on the support cables. Thus it is not necessary to drive pillars into the ground separated in intervals of several meters, as it is often used in PV ground mounted plants. The Solar Wings concept benefits from the long distance between the foundations of the support cables. Intermediate support pillars in the distance of 40 to 100 meters do not need heavy foundation but stabilize the system in terms of wind load and sag of the cables.

Solar Wings Features

- Less than 100kg of steel used to track 1 kW nominal PV power in one- or two-axis configuration
- Support cables carry the electrical DC wiring, no cable trenches needed
- The intermediate support pillars carry the inverter (i.e. 30kW or 100kW) or alternatively the generator junction box.
- PV modules height above ground is selectable, typical 4m, height increase is possible at nominal cost increases, the height is offering an inherent safety, anti-theft protection
- Dual use of the area below the PV plant for parking space or agricultural utilization is possible
- Integration of Solar Wings into building envelope for shading, avoid weight load on roof
- The tracking foundation is done on several points not on a large number of small pillars ramped into the ground, which is favorable for the disassembly of the plant.
- The system is applicable for fixed applications, one-axis or two-axis tracking.

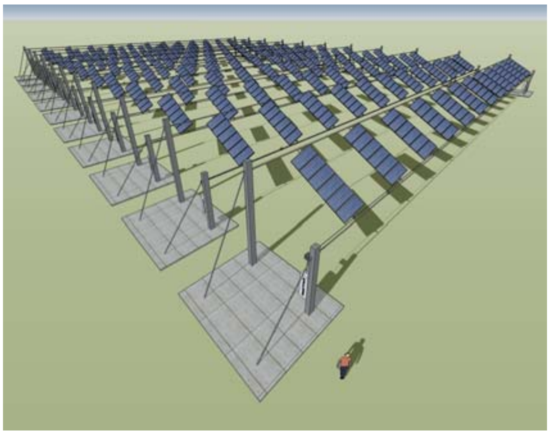

Figure 2: Sketch of Solar Wings mounting system.

2.2 Development Process – Prototype realized

To fulfill the Eurocode requirements of wind load, snow and ice coverage, expert studies were performed by a recognized expert in cable-based applications. Different design concepts have been analyzed in terms of load to the cables as a function of wind speed, wind direction, displacement distance of the PV beams, galloping, resonance and damping. This lead to the construction of the Solar Wings prototype tested in Flums, Switzerland in a region with high wind load due to Foehn-winds (see Figure 3). Various mechanical stress loads could be tested together with the optimum tilt position of the PV modules in the parking position at high wind speed. In Fig. 4 the PV module assembly is shown, mounted on the support cable. All PV module assemblies mounted on the support cable are turned simultaneously by the use of one or two actuator cables activated by one linear actuator as shown in Figure 3.

Figure 3: Solar Wings Prototype erected in Flums, Switzerland with a 40m distance between intermediate support pillars. This prototype version is equipped with horizontal PV module axis to allow the utilization of the space below the PV plant as a parking and loading area.

Figure 4: View of the steering cable turning details to rotate the PV plane around the beam carrier axis to follow the daily course of the sun.

2.4 First Solar Wings PV Plant

The first 600kW plant powered by one-axis Solar Wings trackers will be built on top of a waste disposal site of Lonza AG in Waldshut, Germany and will be connected to the grid in December 2008.(see Fig. 5) Only very few foundations are needed due to Solar Wings concept, minimizing the risk of leakage due to a penetration of the waterproof layer under the surface of the waste disposal site.

Technical features: Solar Wings Tracking

- + 17% Energy yield, tilt axis 22°, range of rotation angle: +/-60°
- Linear drive: one three-phase AC motor to track each 100kW modules
- Industrial SPC Storage Program Control unit; time controlled tracking
- Sensors: wind, temperature, snow, force
- Automatic adjustment of panel orientation at high wind loads
- BOS components: Electrical wiring is supported by cables of Solar Wings system, inverters mounted at intermediate pillars.

The inverters are mounted on the intermediate pillar of the tracking systems, and the electrical wiring is supported by the support cables avoiding standard cable trenches (see Fig. 6).

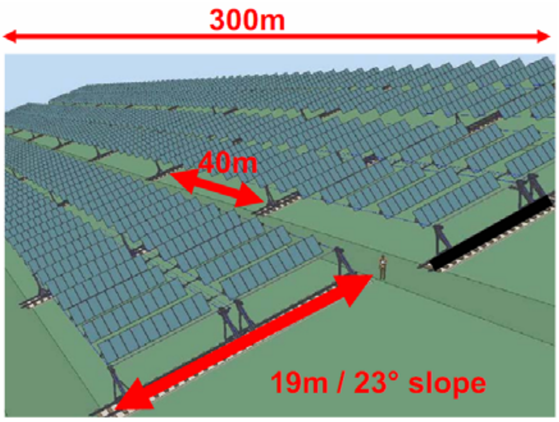

Figure 5: The 600kW plant is grouped in three equal fields mounted on Solar Wings tracking axis. The axis are parallel to the 22° slope relative to horizontal and 20° oriented toward west relative to south.

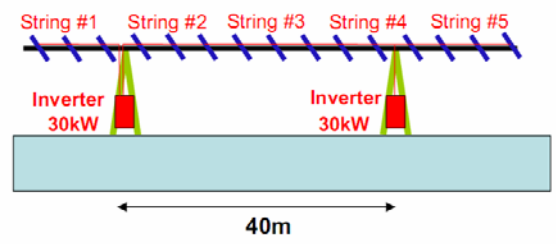

Figure 6: Solar Wings support BOS integration.

3 TWO-AXIS TRACKING: TRACKING WINGS

Further improvement in energy yield can be gained by two-axis tracking (see Tab. II). The Solar Wings one-axis tracker can be easily transformed into a two-axis Tracking Systems as shown in Fig. 7 by adding an additional linear actuator to adjust the PV Modules seasonally for an optimal energy yield. Thus a reliable and cost-effective two-axis tracking system can be realized, with only a minor increase in raw material required. Moreover, adjustment of the second axis is also accomplished with a cable-based tracking mechanism requiring only one additional linear actuator for a large row of solar modules (>100kWp). A first prototype plant is scheduled to be realized this year.

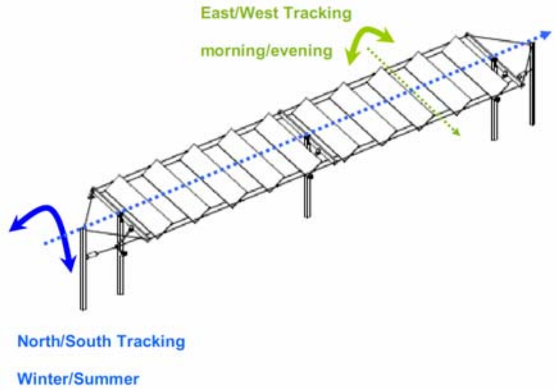

Figure 7: Tracking Wings a two-axis PV tracker [12]

4 OUTLOOK - NEW CONCEPTS

4.1 Concepts of low-concentration

To get even more electrical power out from the PV module concentration of the sunlight is necessary. The Solar Wings low-concentration approach applies mirrors mounted on parallel axis to the PV modules on the same support cables and tracked individually.

4.2 Experimental setup

A flexible experimental test-setup was built at the University ZHAW to measure the gain in electricity production of a mini-module in several different configurations, concentrating the sunlight by the means of planar mirrors individually tracked by stepper motors.

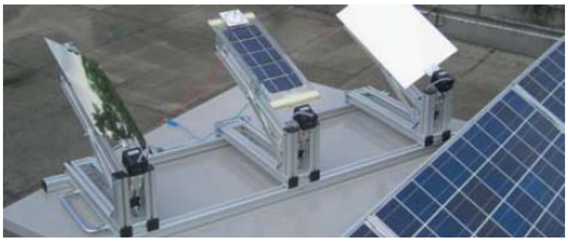

Figure 8: Experimental setup to measure the power gain of low-concentration using parallel tracking axis.

Features of the Test-setup [15]:

- PV mini-module i.e. two 5 inch cryst. Silicon solar cells
- Temperature sensor PT100 integrated in the laminate
- Mirror: Planar Aluminium reflector used
- Tracking mechanism: Each axis is controlled by an individual stepper motor. The inclination angle of the axis is changed manually
- Irradiance sensor measure diffuse and direct light by pyranometers

4.3 Test results of tracking and low concentration

Several outdoor tests were performed at the ZHAW in Winterthur by the use of the test-setup (Fig.8). In Fig 9 the measured short circuit current of the mini-module is shown on a typical clear sky day for a fixed inclination of 35°, the classical tracking to normal incident of the direct sunlight. Additionally, the result of a low-concentration configuration with one planar mirror is shown. This mirror is tracked to the sun in such a way to increase the irradiance on the PV module while the PV module axis is tracked in an optimum position to homogeneously absorb the addition sunlight across the PV mini-module (Fig. 9). Using that tracking variant the irradiance of direct sun onto the PV module is not perpendicular any more. A maximum of collected solar power is reached in the afternoon with a gain of about 30% relative to the maximum value of the fixed installation measured at noon. Summing up the gain of the measured short-circuit current between 10:00 and 18:00 a overall value of 120% due to classical tracking and 152% due to tracking plus the use of one additional tracked mirror is found (Fig. 9)

In that arrangement the distance of both axis and the ratio of the PV module and the mirror width can further be optimized. With an ideal mirror and equal width of mirror and PV module the theoretical maximum will be reached at noon by a gain in input energy of 41%.

Higher irradiance on the PV module is reached by using two planar mirrors mounted on one tracked mirror axis in a fixed angle to each other. (see Fig. 10). The corresponding measurement results demonstrated an increase in short-circuit current of the PV modules of up to 70% relative to the fixed installation at noon and even higher in the late afternoon.

In Fig. 12 the course of the typical daily solar input power is shown for classical tracking the direct sunlight, together with tracking of the PV module assisted by low-concentration due to the use of mirrors.

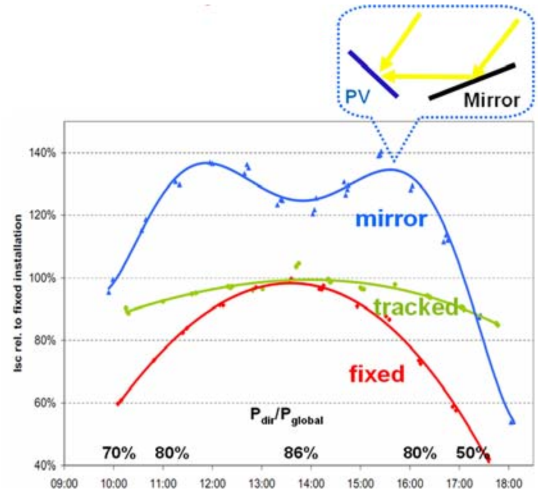

Figure 9: Outdoor measurement results of short-circuit current using the test-setup (Fig. 8) and tracking the PV module assisted by the use of one planar mirror to increase sunlight irradiance. The outdoor measurement was performed in Winterthur on the 2008-08-27 with measured ratio of direct to global irradiance in the horizontal plane of 70% at 10:00, 86% at noon and 50% at 17:00.

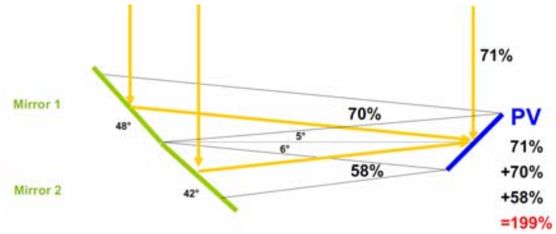

Figure 10: Low-concentration using two planar mirrors.

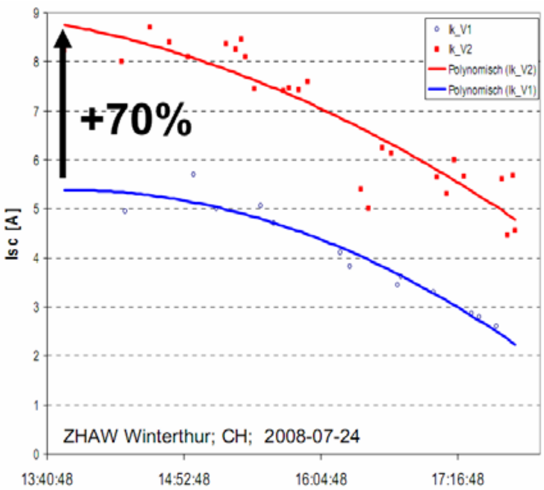

Figure 11: Outdoor measurement results of short-circuit current using the test-setup (Fig. 8) and tracking the PV module assisted by the use of two planar mirrors (Fig. 10) to increase sunlight irradiance. Measurement performed at Winterthur, Switzerland on the 2008-07-24.

Figure 12: Typical characteristics of solar input during the course of a day of classical tracking and individually tracking of PV modules and mirrors to reach low-concentration (latitude 47° north, all tracking axis are parallel).

4.4 Power Wings: Tracking plus low-concentration

The two-axis Tracking Wings system will be additionally equipped with independently tracked mirrors to realize low-concentration of sunlight by using the benefits of the cable based system (Fig. 7)

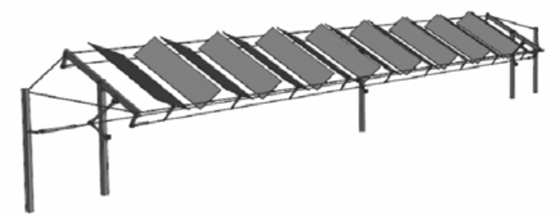

Figure 13: Power Wings is a two axis Solar Wings tracking system completed by an independently tracked mirror system with parallel tracking axis mounted on the same two support cables.[13]

7 SUMMARY

A cable-based mounting system has been investigated and shown to be a viable alternative to traditional mounting systems. Robust cable-based PV mounting systems can be realized with far less raw material than traditional systems. One common drive can activate a large number of cable-linked module assemblies, minimizing the number of drive components of the PV tracker.

Double use of land for PV plants with cable based systems is recommended, because a height of > 3m above ground can be implemented at nominal cost increases for cable based systems. Moreover, cable-based PV systems offer advantages to support electrical wiring.

- A prototype one axis tracker has been realized and tested.
- The first Solar Wings system sized with 600kWp will be realized this year.
- Cable-based systems are also suitable for two axis tracking and a first two axis prototype will be realized this year.
- A development project using low-concentration of sunlight on small scale table with low-cost planar mirrors has demonstrated the additional energy yield.

Tests at kW level based on the Solar Wings tracking system are planned for 2009.

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