SUNSPEAR CALIBRATION AGAINST ARRAY POWER OUTPUT FOR TRACKING ACCURACY MONITORING IN SOLAR CONCENTRATORS

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ABSTRACT: Current sun trackers for concentrating photovoltaic (CPV) modules rely on two general kinds of tracking strategies. Some make use of the computational ephemerides to predict the solar vector at any time. In others, a closed loop feedback strategy, based on a sun sensor, is used. Independently from the technology used, once the tracker is calibrated, control systems stop checking the array power output and focus on either a sun sensor or calculated parameters to track the sun. There is no way to know if the tracker is correctly maintained at its maximum power orientation while tracking instantaneously and without disconnecting the production from the grid. Inspira has developed a sensor and related instrumentation systems to measure the pointing angle error called SunSpear® [2] based on a solid state image sensor housed in a collimating tube. Consequently, a method is described to calibrate this device against the real DC array power output in which we can also reflect structure deformations. Once this instrument is calibrated we can achieve a highly precise measurement of the off tracking angle related with the maximum power orientation in real time, without disconnecting the array from the inverter. This procedure enables a more accurate tracking measurements and monitoring for CPV systems, because it is related to the tracker's departure from the maximum power output orientation.

Keywords: Concentrators, Tracking, Monitoring

1 INTRODUCTION

Every CPV module is designed to be perfectly pointed at the sun in order to get the maximum power of it. But this alignment could not be perfect because the module is composed of small cells that get some misalignment during its assembling. This makes the maximum power vector of the module, to be the best compromise of the maximum pointing power points that every single cell has. We can repeat the same study when we work with trackers and try to obtain the best maximum pointing axis of the whole array from the ones of every single module.

This maximum vector of the array is the reference for CPV Sun trackers designers who want to maximize the power output of the array by minimizing the alignment error of the local vector of the sun to it. This alignment must be accurate enough to keep it inside of the angular acceptance of the CPV system at all times, and for all the positions of the tracking system.

A CPV tracking system may fail to reach this alignment for many reasons, which can be organized in two main groups; (i) those that affect the alignment of the maximum power vector to the Sun, and (ii) those factors that can affect the global angular acceptance of the system, so a greater alignment is required.

Among those reasons related to the alignment of the pointing vector to the Sun, we can further separate the error sources into two sub-groups. The first are those related to the determination of the sun's local vector. No matter if it uses the ephemerides of the sun or an external sensor mounted on the aperture, or a mix of both, the control system must to have the ability to calculate the current solar vector, and translate that vector into tracker's coordinate system. This calculation must be accurate enough to conserve the pointing error always below a predefined threshold. The second sub-group is the precision with which the system is able to adjust its rotation angles to the previously calculated position. This accuracy depends on aspects of the electromechanical feedback system, such as the resolution with which the rotational position of the axes are measured and the precision with which the actuators can control the axes.

Among those related to those factors that can affect the global angular acceptance of the system, we could also distinguish two different sub-groups. On one side, there is a compromise with the correct alignment when mounting the CPV panel atop the tracker. Therefore this could be resumed in a good design of the mounting system, where all manufactory defects could be resolved by special fixtures provided for this purpose, and a correct execution of an alignment protocol, ensuring the local vector of each panel is placed within a minimum error referred to the local frame vector. On the other, we could find those factors related directly with the materials and the structure design itself, that translates into deformations and shrinkage of the whole system. These ultimate effects could be also increased by some dynamic factors like for instance, the wind, that modifies the global forces are present on a CPV tracker. These dynamic factors could be also to decrease the precision if they synchronize with the natural resonance of the system, making oscillations that could unstable the power production and causing mechanical stresses and electric overloads on motors.

These factors have direct relation with the design of the CPV modules. We must take the aperture of the whole system, as the maximum error permitted, leaving to the tracker designer very hard compromises to achieve. The stricter the configuration setting the panel is designed the more cost and weight tracker will result.

2 SUNSPEAR CALIBRATION FOR TRACKING ACCURACY MONITORING

Determination and characterization of those error sources described previously is crucial when designing the strict service conditions for CPV trackers and must be accomplished from a global perspective, therefore the whole CPV has to be consider as a whole. This task is not easy, and sometimes it's not clear the consequences of every single error, when we try to add them into a global system pointing error.

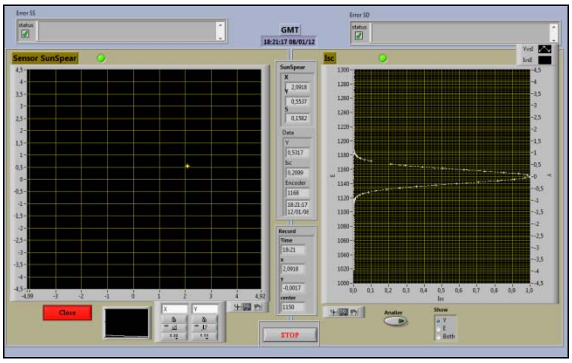
In a first approximation we could distinguish three types of error's sources in order of complexity. First we have to consider the analytic errors, for instance, when we calculate the Sun's ephemerides. Second, we could place the errors made during the installation or when adjusting sensors which affects the precision of the tracker. In the third place we find those errors caused by the intrinsic nature of the materials used, and some dynamic effects that can only be solved by complex Finite Elements analysis applied directly to the tracking structure elements.

Therefore, the two first sources could be measured and corrected with algorithms as Inspira has demonstrated in a former work [2], using the SunSpear® as a virtual power output measure device. We have demonstrated that the precision of the calibrated open loop strategy is better than 0.1º with 97% of probability when using a low backlash tracking drive and low payload trackers. To obtain this result the SunDog® STCU was calibrated against a SunSpear® sensor assuming its perfect central point as a virtual maximum power output.

Aiming to measure and validate the errors achieved when working with the real DC power of the array and commercial trackers, Inspira has developed a measurement algorithm. In this paper we work the other way around by calibrating the SunSpear® to the maximum power output of a CPV array, both being installed in the same tracker. Maximum power output orientation at each tracker position of its aperture is highlighted by the SunSpear as a point in the sensor´s planar surface, which, once the calibration is finished, will be taken as an accurate point for reference to calculate and monitor the real tracking precision and errors of the CPV system.

2.1 Description of the calibration and tracking accuracy monitoring system

An auto-calibrated version of Sundog® Control Unit, with its switching and biasing additional unit, called Mooncat, is used to perform the switching of the whole array to short-circuit, and make measurements of the current. A SunSpear® device is installed in the aperture surface on the same beam the modules are fixed. As a final point, the version of SunSpear® had to be modified to cover the full range of the current curves by reducing the length of its collimated tube, which therefore provokes an increase of the view of sight up to 2.6º.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Isc 0,2099
Encoder 1168
18:21:17 12/01/08

Record
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center 1150

Figure 1: Instrumentation software, (left) surface of the SunSpear® sensor showing the collimated sunspot like a yellow cross, (right) short circuit current curve during the scanning in one axis

Both devices, SunDog® and SunSpear® communicate in parallel through a serial connection with a central computer, supplying the PQ spot coordinates in the SunSpear® plane and the instantaneous current read.

Angle positions, from the two tracking axes and current readings, are time-traced by the Sundog® internal real time clock, and recorded in the central computer. Finally, this computer runs the software as shown in Fig.1, for its final internal processing, presentation and storage in a log file. Lately, it is used another program to analyze and processing the data recorded, which is presented to the user.

2.2 SunSpear® calibration procedure algorithm

Before accepting any coordinates for its positions, a biasing unit forces a short-circuit affecting the full array. To precise the most accurate pointing data in the SunSpear® surface, when the maximum power is achieved, a sun searching routine is carried out by the tracker. Measures of the current and the position that gives the SunSpear® are recorded and the maximum is calculated by interpolating the flanks of the curve versus the correspondent P or Q position, and take as maximum point the central point of between those straight lines at the 50% of dropping current.

With the CPV tracker in its calibration mode, the searching algorithm proceeds as follows:

- The Az. Axis makes a sweep of ±7º with constant velocity around the calculated tracking position and the maximum power output readings, or alternative equivalent, and recorded to undergo the statistical processing described that locates the maximum on the P-axis
- The El. Axis equivalently makes a sweep of ±7º around the above maximum in P-axis and the calculated El. tracking coordinate, getting as a result the maximum position in Q-axis.

This procedure is really appropriate for pedestal AZ-EL. Trackers, in which we can assume that maximum power positions in the sensor's planar surface follows a vertical path line, which we can interpolate from the data. The first Az. maximization measurement provides the P coordinates, while the subsequent El. maximizations provide the Q coordinates at each tracker elevation.

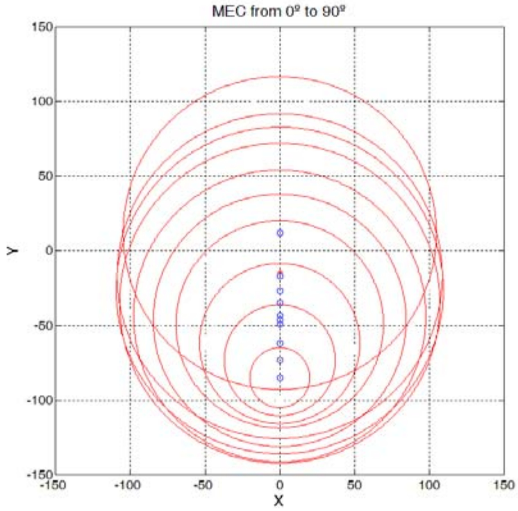

Figure 2: Analytic simulation of point which represents the maximum power vector, showing a vertical trend when the tracker is placed at different elevations, caused by flexure.

The calibration process will allow us to known the position of the maximum power in SunSpear surface as a function of the elevation and azimuth location of the Sun. Then we can compare this result with the tracking data deducing the misalignment of the tracker.

3 CALIBRATION OF THE SUNSPEAR AGAINST THE MAXIMUM POWER

In this section, we are going to describe the result obtained following the process explained before, using a real tracker of 48m^2 of aperture and with more than 2 tons of payload on top. Every single CPV module on its surface was placed with a fitting protocol that guaranteed a maximum alignment error of less than 0.1º measured in either axis to the ground's perpendicular vector. Finally a modified version of SunSpear® with a wider aperture of 2.8º was placed on top.

The calibration algorithm used during the day give us sampling points which represent where is the maximum point vector placed on the SunSpear® surface. We could get a figure like the one represented on Fig. 3 placing the points calculated in the Q-axis and comparing them with the elevation of the sun a given time. As showed on the graph, there is a relation between the position in elevation and the drift of the Q maximum position as expected.

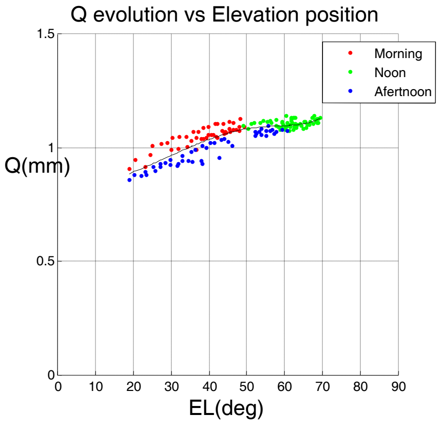

Figure 3: Representation of the maximum drift in the Q-axis, versus the elevation angle position. Data interpolation is showed as a black line.

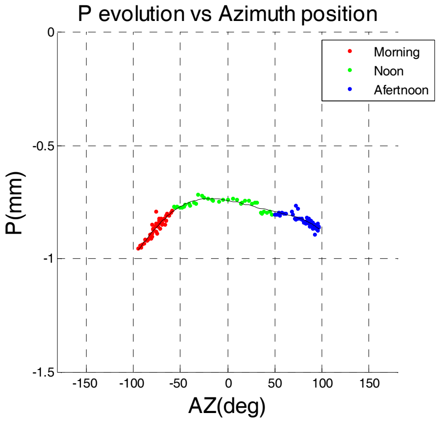

Figure 4: Representation of the drift of the maximum in the P-axis, versus the Azimuth position. Data interpolation is showed as a black line

More over, we can continue the same study in the P axis finding that there is a drift different from zero. Making the relationship between this axis and the AZ axis, we get the following Fig. 4.

But, we cannot compare those points because they were taken at different times, nevertheless let's perform a statistical interpolation for each axis, using a minimum square fitting algorithm, getting as a result the following equations which determines the position of the maximum, defined by the P,Q pair of points, for every pair of AZ, EL entry.

$$P_{\max} = \sum_{i=0}^{i<N} a_i \theta_{AZ}{}^{i}$$

$$Q_{\max} = \sum_{i=0}^{i<N} b_i \gamma_{EL}{}^{i}$$

The group of vectors named as *a, b* represent then the parametric calibration of the system. For the purpose of this experiment we try to minimize minimum quadratic error given a value to N equal to 5, giving us a representation of the path of the maximum for a specific day. Fig. 5 shows us the evolution of this point. There were also drawn on the surface some circles which represents points with equal current values, at 95% of the maximum, from the current curve samples. Red positions indicate data collected during the morning, green for the noon and finally blue for afternoon.

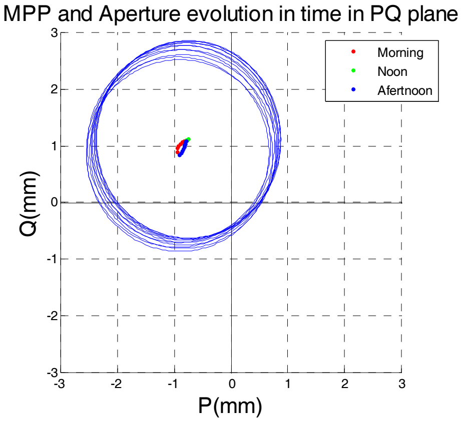

Figure 5: Representation of the path's approximation of the maximum power vector in the surface of the sensor, during a day, caused by flexure. Circles in blue indicate the aperture of the system.

4 RELATIVE ERROR MEASUREMENTS

Once we have the maximum power vector represented on the surface of the SunSpear®, we might easily find the relative errors, as the angular distance of the tracking point during a day, to this dynamic maximum. Let's then, use the following algorithm to represent the evolution of the error along one day.

Tracker was left to follow the sun in a tracking mode during the daylight, and data was recorded letting the SunSpear® itself to register the position of the Sun spot on the surface for each second. After this daily-data samples, it was calculated the difference, in terms of spatial distance on the PQ plane, from the point registered and the maximum previously represented for those (AZ, EL) positions; in other words, (AZ, EL) positions of the sun was calculated for the time stamp fixed by the sample, then using the equations previously calculated to represent the maximum, it can be inferred where is the maximum for that sample. Using that relative difference, we can transform the center of the following graph as the static maximum point center, and represent the ΔQ and ΔP on the surface. Applying this procedure for the rest of samples of the day, gives us the following Fig. 5. Colored data represents the time fraction the Sun spot was on that area. Colors go from blue to red, indicating a low to high fraction of time respectively. Also in the graphic we can see some reference rings to help us measuring the angular errors

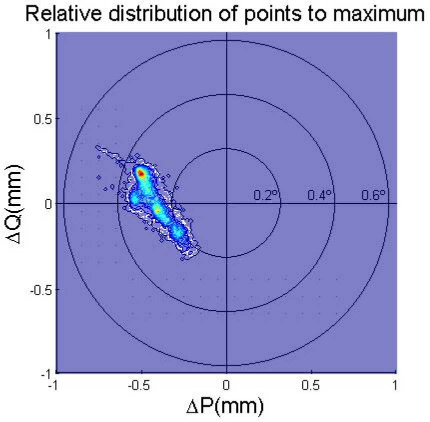

Figure 5: Representation of the relative distance to the maximum power vector along one day. Data colored from blue to red indicates the time fraction, from low to high; the sun spot was on that area during the sampling. Rings presented on the surface indicate the points with constant angle of 0.2º, 0.4º and 0.6º.

4.1 Final statistic analysis

Once we have calculated the spatial error made we can transform it to the angular distance between points to the center with elementary trigonometry.

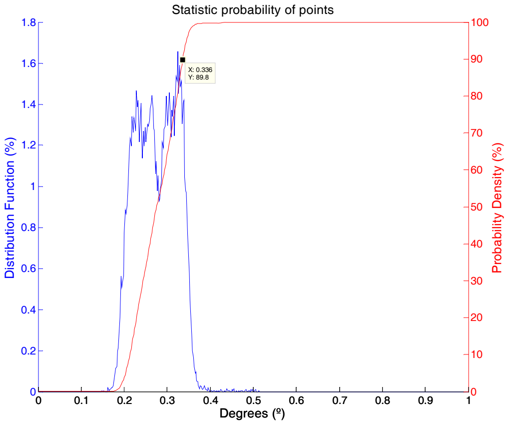

Figure 6: Statistic distribution of the angular distance to the maximum point during one full day. The text box on the curve indicates the cut where the samples were less than 0.33º far from the maximum power point with a 89% of probability for that system. Probability density is marked in red on right and the distribution function is colored in blue on left.

After having the angular distance for each point during the day, the probability of error and the cumulative probability are calculated and determined the maximum circle (or angle) where the 90% of the points are inscribed. Then we can accept this value a measure of the quality of the whole system. You can view on Fig. 6 the evolution of the probability.

5 CONCLUSION

We begin the study form a strict bounding condition as starting point, with the definition of the local pointing vector and the small errors needed to achieve in CPV systems and the direct relationship when a CPV tracker design is performed. This design must cover and think on all the possible sources of errors that could occur on a tracker and notice that is not needed only to track correctly the local vector of the sun, but also to take care about the size and deformations of the frame, which are a cause of a global drift of the local frame vector when pointing at the Sun.

On previous work, it was demonstrated some strategies to fulfil the starting design criterion, but once the mechanical stresses are introduced by increasing the size and weight of the tracker, the misalignment of the calibrated point becomes more and more evident

The calibration procedure presented here might be an excellent method to determine the quality, the system will be able to harvest the maximum energy, and used as an analyzer of the mechanical defects and deformations the structure is suffering. Finally, parameters taken from the power calibration versus the SunSpear®, makes possible to improve an open-loop tracking algorithm by inserting these calculated errors to the equations.

6 REFERENCES

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