AUTOMATION OF THE CALIBRATION PROCESS IN THE SUNDOG® STCU

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ABSTRACT: open loop strategies base its calculation on two different parameters. Time and location of the equation are only needed to calculate and predict the Sun's position. This method is accurate for just the location point we are calculating but start to fail when we move our reference point to the tracker references. Placing our coordinate system on the tracker imply that we have to know the perfect position of each axis, but this is very difficult to know in the real trackers and they could change between one and another. The calibration of the controller is need. The problem of the calibration is procedure can be long and not very inaccurate if it is done manually. The objective of the paper is to present why the automation of the calibration process is important and describe how it can be realized.
Keywords: Concentrators, Tracking, Calibration

1 INTRODUCTION

This paper aims to describe the automated calibration process of a tracker using the SunDog® STCU. The SunDog® STCU is an open-loop controller based in sun ephemeris computation with a calibration error model on top to convert sun coordinates to tracker axes rotation angles [1],[2],[3], which has been developed specifically for concentrated photovoltaic (CPV) applications. Calibration is the process of taking a set of measurements of the precise location of the sun in terms of tracking axes angles and feeding these into a calibration. A set of best fit parameters is obtained such that the calibration model produce the accurate conversion from solar coordinates to axes turning angles. The parameters of the error model are specific to each tracker, so a calibration process must be done when the tracker is mounted in field.

Calibration is therefore the process of precisely aiming the array of CPV modules to the sun and comparing its position with the theoretical one given by the sun ephemeris equations. Whatever the algorithm followed to point the concentrator to the sun, we assume as best aiming orientation that producing the maximum power output. This sun location process must be repeated through out the whole day to get the most homogeneous set of samples.

There are two reasons to automate the calibration process. The first is to try to minimize the installation and configuration time of the STCU. For a solar plant of hundreds or thousands of trackers it is impossible to have one technician spending one day to calibrate each concentrator. So to decrease the installation time and thus the installation cost the controller needs to be more and more like a "Plug & Play" product, with minimum human intervention. Secondly, the calibration process when done manually is compromised mostly because of the repetitive and tiresome process, and accuracy may be compromised due to human error.

2 AUTOCALIBRATION PROCESS

However the automation of the calibration process creates new problems. One of them derives from the fact that to make a sun position measurement we first have to get the concentrator's pointing vector – that which aligned with the sun vector produces maximum power output – inside the concentrator's acceptance angle, and at the beginning the controller does not have any prior knowledge of what its reference system is with respect to the sun ephemeris topocentric reference. To solve this problem a small conventional PV module can be used. Fixed on the same plane as the CPV modules it is used by the controller to find a first approximation of the sun position. In fact with two full scans, one per axis, the controller can compute an approximation of it is offset parameters that maximize the output current of the PV module. During the scan the controller is not only looking for the maximum, but it is also analyzing the variation of the production of the PV module in order to identify those changes, that are attributed to artifacts such as clouds, shadows from the terrain, shadow from other trackers etc… The controller must be able to differentiate between a local maximum caused by such artifacts and the global maximum caused by the best alignment between the PV module and the sun. This is very important because this will be the new starting point. We have found that this initial scan can locate the sun´s position with an accuracy on the order of 5º. However it is likely that the solar vector is still outside of the angular aperture of the CPV module array, so a second scan of the tracking space must then be initiated.

Power output maximization can be assumed to be a close equivalent of short circuit current maximization. To measure the I_{sc} of the modules, the SunDog® STCU is coupled with a switching box (MoonCat), essentially composed of two IGBTs (one to connect to load and one for the CPV array shorting) and one Hall effect sensor for measuring the current of the CPV array. When reading I_{sc} either when scanning to enter in the array's acceptance angle or once in maximizing $I_{sc,}$ the array is shorted and for this purpose the IGBT switches are directly controlled by the STCU

The scanning method used for this second step follows a rectangular spiral, alternating azimuth and elevation movement. (Fig 1) The step between each leg of the spiral must be big enough not to make the spiral dynamics too slow but on the other hand small enough not to miss the sun in its progress. This optimum step is dependent on the angular aperture of CPV modules used: the larger aperture of the CPV module the greater the step size that may be used. Once the I_{sc} as measured by the Hall effect sensor surpasses a certain threshold, it can be assumed that the solar vector has entered the anglular aperture of the CPV array, so we may stop this spiral search and start the last scanning routine. For the squared spiral, the controller has to take in account its tracking limit. The tracker has a limited range, so the spiral can not be infinite. If the next step of the spiral is beyond the tracking limit, the algorithm simply ceases to gro the spiral in that direction.

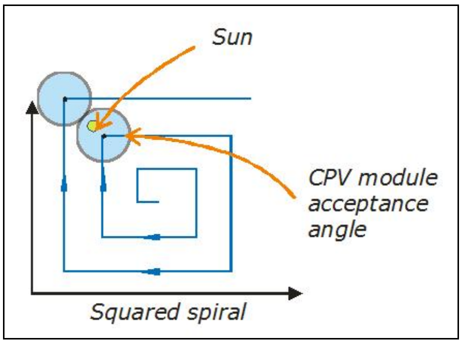

Fig 1: Squared spiral method.

This position the CPV array's acceptance angle, the controller is used as a second approximation of the sun, however this measurement will not be record for the model parameter system resolution. The final step is to maximize the I_{sc} consecutively in the two axes, first in azimuth then in elevation. This will provide two measurements, each one with a precise time stamp. Due to noise in the readings, filtering through interpolation is applied onto the angle readings. This can be seen in the figures 2 below for sun position measurements in the elevation axis, before and after applying filtering through interpolation.

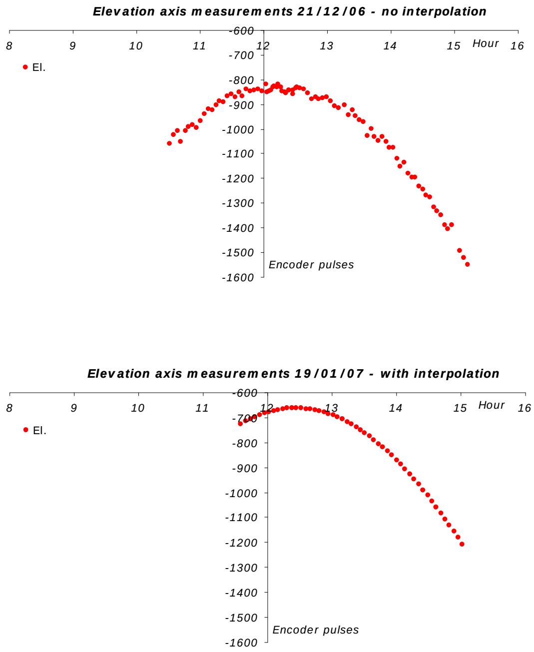

Fig 2: Difference between a calibration without noise filtering and a calibration with straight lines approximation.

In addition, a straight line interpolation method is used to find the maximum power point from the I_{sc} readings. This consists in taking the flanks of the curve, between 25%-75% of the peak of the current read by the STCU, fitting a line to each flank, and locating the midpoint between positions with the same current (50% of the peak of the current read). An example of this method is represented in the figure 3.

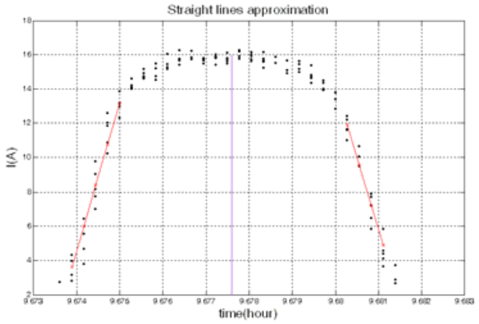

Fig 3: Interpolation method. In green the interpolation of the growing flank, in blue the interpolation of the decreasing flank. In the middle, the straight line represents the computed central point.

After the first measurement, the following ones are less time consuming because sun tracking can using a correction based on the tracking axes offsets with respect to the computed ephemeris obtained from the first reading. In this way, only the third step of the calibration needs to be repeated for the following measurements as tracker the tracker generally remains within acceptance angle in between measurements, even when tracking based on a rough calibration. Calibration will proceed until a set number of measurements in an equivalent fully clear day, from dawn to dusk, are completed.

Because a precise calibration results in higher energy generation for the life of the system, the strategy of Inspira algorithm is quite strict when it comes to measurement quality. Through-out calibration the STCU is checking and analyzing all the variation on the PV module output and compare it with the change on the current measurement. Therefore, the SunDog® STCU is able to stop the calibration if a cloud is detected by the PV module.

Homogeneous distribution of measurements during a fully clear day is important for the gathering of a set that will produce the most accurate fitting of the calibration model. The calibration uses a preset number of measurements to calculate best-fit calibration, and these measurements are distributed in predefined time slots in order to achieve this homogeneity. Until all the measurements planned for each segment are completed, the calibration will not model fitting for that segment. Therefore we can see the advantage of using a full automatic calibration system. If one of the segment still need some measurements, during the rest of the segments the system will be generating power, using the last tracking axes offsets as input.

3 TEST

A 1kWp CPV system designed by Inspira around Daido Steel's concentration modules (see Fig 4) was used as a test bed for the development and testing of this autocalibration routines. This test bed has been very useful for the testing of the scanning and maximization routines, the sizing of the switching devices taking into account real CPV array transients, and finally the long term testing of autocalibration sequences with different numbers of total measurements and time slots to assess the optimum number of measurements and time slots that will reduce the most the autocalibration time without compromising fitting accuracy (see Fig2). The results of this last set of experiments is presented here.

Fig 4: Inspira's 1kWp test bed with Daido Steel's CPV modules

Once the auto calibration software was completed, a battery of tests was carried out in which the number of segments and number of measurements per segment were varied seeking to determine which scheme would be the least time consuming, while still producing corrected ephemeris with sufficent accuracy. Table 1 describes the different arrangement of each test case followed out.

Split	Total measurements	Measurement distribution
3	30	10/10/10
3	60	20/20/20
3	120	40/40/40
5	30	6/6/6/6/6
5	60	12/12/12/12/12
5	120	24/24/24/24/24
7	30	5/4/4/4/4/4/5
7	60	9/9/8/8/8/9/9
7	120	17/17/17/18/17/17/17

Table 1: The different configuration tested.

After fitting the calibration model and obtaining its six best fit parameters, an estimate of the accuracy of the corrected ephemeris was obtained by obtaining the mean error for all the 625 sun position measurements and the computed sun position at the same days and time instants than the measurements. The mean errors for each of the different corrected ephemeris are displayed in Table 2.

Split	Total measurements	Days	Measurement distribution	Mean Error (º)
3	30	1	10/10/10	0,028751
3	60	2	20/20/20	0,29802
3	120	3	40/40/40	0,025123
5	30	7	6/6/6/6/6	0,032795
5	60	3	12/12/12/12/12	0,02903
5	120	5	24/24/24/24/24	0,033902
7	30	5	5/4/4/4/4/4/5	0,033204
7	60	7	9/9/8/8/8/9/9	0,02972
7	115	6	5/17/17/18/17/17/15	0,031207

Table 2: Main result of the full sets of calibration.

For the best case mean error is 0,025123º, however we must keep in mind that the mean tracking accuracy of the ephemeris coded in the sun tracking control unit is 0,0025º when calculated in a desktop computer, but that grows to 0,029º when computed in the 8 bit microcontroller used by the sun tracking control unit. this means that the effect of converting the ephemeris to tracking axes turns results in a 0,02º loss in average accuracy.

This study shows that although the homogenous of the samples is very important for the accuracy of the model parameter system, the quantity of samples is not the most important criterion. In fact with a 8 bit microprocessor the difference between 30 or 120 samples is insignificant. Therefore, the sample gathering methodology should be selected in order to minimize the amount of time used to calibrate instead of generate electricity. Using this criterion, the case of 30 samples split over three segments should be chosen, because is sufficiently accurate, and uses the least amount of time. Because the MoonCat provides automatic switching between calibration and generation modes, the system is producing power during between each segment.

Following these tests, the autocalibration routine has been tested with a number of different CPV module technologies for which Inspira has designed and manufactured CPV trackers. The most advanced those participating in the ISFOC CPV demonstration, i.e. SolFocus, Concentrix and Concentración Solar La Mancha. This has not only enabled the testing of these autocalibration routines in the actual power plant situations, but also allowed us to develop the procedures for sizing of the switching and biasing units involved in the different technologies at full-scale operational powers.

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