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Application of new control strategy for sun tracking

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Abstract

The application of high concentration solar cells technology allows a significant increase in the amount of energy collected by solar arrays per unit area. However, to make it possible, more severe specifications on the sun pointing error are required. In fact, the performance of solar cells with concentrators decreases drastically if this error is greater than a small value. These specifications are not fulfilled by simple tracking systems due to different sources of errors (e.g., small misalignments of the structure with respect to geographical north) that appear in practice in low cost, domestic applications.

This paper presents a control application of a sun tracker that is able to follow the sun with high accuracy without the necessity of either a precise procedure of installation or recalibration. A hybrid tracking system that consists of a combination of open loop tracking strategies based on solar movement models and closed loop strategies using a dynamic feedback controller is presented. Energy saving factors are taken into account, which implies that, among other factors, the sun is not constantly tracked with the same accuracy, to prevent energy overconsumption by the motors. Simulation and experimental results with a low cost two axes solar tracker are exposed, including a comparison between a classical open loop tracking strategy and the proposed hybrid one.
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Keywords: Closed loop control; Sun tracking strategy; Low cost two axes solar tracker; Robust performance

1. Introduction

Thanks to the technical advances, reasonable priced high concentration solar photovoltaics (PV) arrays are supposed to be available within a close time. However, the future use of this kind of solar PV arrays in low cost installations will bring a new type of problem: the necessity of high accuracy solar pointing. High concentration solar PV arrays require greater solar tracking precision than conventional photovoltaic arrays, and therefore, a relatively low pointing error must be achieved for this class of installations. Since, in large plants, the design and installation is optimized, they can usually achieve this low error requirement. Nevertheless, the cost of such optimization is prohibitive for low cost installations.

This paper discusses the design and implementation of a control algorithm for a low cost mechanical structure that can support photovoltaic modules and that acts as a sun tracker.

Several classes of structure can be distinguished depending on the classification criteria:

- Regarding movement capability, three main types of sun trackers exist [1]: fixed surfaces, one axis trackers (see [2]) and two axes trackers (see [3]). The main difference among them is the ability to reduce the pointing error, increasing the daily irradiation that the solar cells receive and, thus, the electric energy that they produce. A theoretical comparative study between the energy available to a two axes tracker, an east–west tracker and a fixed surface was presented in [4]. As main results, it concluded that the annual energy available to the ideal tracker is higher by 5–10% and 50% than the east–west tracker and the fixed surface, respectively.

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- Regarding control units, the main types of solar trackers are [5]: passive, microprocessor and electro-optical controlled units. The first ones do not use any electronic control or motor (see [6]). The second ones use mathematical formulae to predict the sun's movement and need not sense the sunlight. An example of this kind of unit can be found in [3]. Finally, the electro-optical controlled units that use the information of some kind of sensor (e.g., auxiliary bifacial solar cell panel, pyrheliometer) to estimate the sun's real position is used in the control algorithm (see [2,7]).

This paper presents a control strategy for two axes trackers that is executed in a microprocessor. Correct pointing is inferred from the generated electrical power, which must be sensed on line.

The proposed control strategy consists of a combination between: (1) An open loop tracking strategy, which corresponds to the *microprocessor controller* in the classification [5]. This controller is based on a solar movement model. (2) A closed loop strategy, which corresponds to the *electro-optical controller* in the previous classification. This strategy consists of a dynamic controller that feeds back generated power measurements.

Furthermore, in order to make the system autonomous, a search mode that operates when the tracking error is too large is included. To prevent the system from going into the search mode too often, a reduced table of errors (updated every half an hour if there is enough radiation) is also stored.

The main differences between this strategy and the ones presented in other works, such as [7] or [8], with similar purposes are the following:

- Those works deal with open loop control and with estimated pointing errors. These errors are stored for later analysis. Thus, those strategies do not use on line feedback control, while ours uses a dynamic controller.
- A large amount of memory is needed to hold the stored error database in those works. This problem would be more serious if a two axes tracker was used. This fact requires that new hardware be used for control purposes. Thereby, those algorithms are not useful when a small amount of memory is available. In this case, the combination of on line feedback control and a quite small error table is more than sufficient to make the system work with the required precision.
- In addition, energy saving factors are taken into account in the proposed strategy. This implies that, among other factors, the sun is not constantly tracked with the same accuracy to prevent energy overconsumption by the motors.

The control algorithm takes into account the different types of errors that can appear in practice in low cost domestic systems, e.g., the placement and problems with the mechanical structure and errors of time and location. As a result, whatever the type of error, the controller can make the tracker follow the sun. In fact, the proposed algorithm is also valid for large high precision trackers since it contributes to decreasing these errors.

In summary, there are three main aspects concerned with this control strategy:

- A new sun tracking strategy for low cost positioners with two degrees of freedom was developed.
- A simulator that allows us to evaluate how the tracking strategy is working as well as to program other strategies was built.
- A mechanical structure that acts as a solar tracker and a monitoring and positioning control system for two degrees of freedom was built (see pictures of the tracker in Fig. 11).

The remainder of the paper is organized as follows: the tracking strategy is explained in detail in Section 2. Section 3 describes the structure of the control system. Experimental results, including a comparison between an open loop and the proposed hybrid strategies, are shown Section 4. Finally, the main conclusions of this work are drawn in Section 5.

2. Automatic tracking strategy

A hybrid tracking strategy that basically consists of two modes was used: in one mode, normal sun tracking is performed, maintaining a tracking error less than a pre-specified value. In the other, a sun search is undertaken by means of an ever widening rectangular spiral; this is necessary when the sun needs to be located because of some external disturbance (for example, a period of prolonged cloudiness). Each of these modes is described in greater detail below.

2.1. Normal tracking mode

This mode is in effect whenever the sun tracking error is smaller than a specified bound and the solar radiation great enough for the system to produce electric energy.

It is a hybrid tracking system that consists of a combination of open loop tracking strategies based on solar movement models (feedforward control) and closed loop control strategies using a feedback controller. The feedback controller is designed to correct the tracking errors made by the feedforward controller in the open loop mode. The operation in this mode is shown schematically in Fig. 1.

In this figure, u represents the position (azimuth and elevation) the tracking system assumes is the location of the sun. It can be seen that this estimated position of the sun is obtained by adding two values: $\bar{u}$, which is the position obtained from the equations that model the sun's movement, and $\tilde{u}$, which is a correction of that position based on the estimated position of the sun, $\bar{y}$.

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