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Direct tracking error characterization on a single-axis solar tracker

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ABSTRACT

The solar trackers are devices used to orientate solar concentrating systems in order to increase the focusing of the solar radiation on a receiver. A solar concentrator with a medium or high concentration ratio needs to be orientated correctly by an accurate solar tracking mechanism to avoid losing the sunrays out from the receiver. Hence, to obtain an appropriate operation, it is important to know the accuracy of a solar tracker in regard to the required precision of the concentrator in order to maximize the collector optical efficiency. A procedure for the characterization of the accuracy of a solar tracker is presented for a single-axis solar tracker. More precisely, this study focuses on the estimation of the positioning angle error of a parabolic trough collector using a direct procedure. A testing procedure, adapted from the International standard IEC 62817 for photovoltaic trackers, was defined. The results show that the angular tracking error was within ±0.4° for this tracker. The optical losses due to the tracking were calculated using the longitudinal incidence angle modifier obtained by ray-tracing simulation. The acceptance angles for various transversal angles were analyzed, and the average optical loss, due to the tracking, was 0.317% during the whole testing campaign. The procedure presented in this work showed that the tracker precision was adequate for the requirements of the analyzed optical system.

1. Introduction

The method to determine the precision of a solar tracker used in solar thermal collectors has not yet been standardized. Nowadays, existing testing standards for solar collectors consider a solar tracker as a part of the collector [1]. Thus, the losses of efficiency due to tracking imprecision are not quantified in the global collector efficiency test.

The International standard IEC 62817 [2] enables to certify solar trackers for photovoltaic applications considering both accuracy and durability. However, this standard accuracy test is not applicable to solar thermal concentrator tracker, particularly to single-axis solar tracker for linear solar concentrator.

The Spanish committee AEN CTN 206/SC 117 [3] redacted a proposal to the international committee IEC 117 [4], for the standard characterization of parabolic-trough collector (PTC) solar trackers which led to the creation of a working group for a new standard draft approved in November 2014 [5].

According to Mousazadeh et al. [6], solar trackers are classified according to their orientation (one or two axes) and their actuation (active or passive, and open or closed loop). Depending on the type of collector, different solar tracking systems rely on different tracking strategies. For example, for the Fixed Mirror [7] the receiver is the only moving component, while for the PTC [8], the whole system (mirror and absorber) tracks the sun direction at the same time. The present paper is focused on a small-sized PTC with active loop.

In order to identify the tracking error of a solar tracker, devices similar to the sun-sensor on a closed-loop actuation tracker can be used. However, the characterization of the tracking error requires a highly accurate electronic device. Since 1987, when Bhatnagar et al. [9] experimentally measured the average tracking error of a parabolic concentrator with a single-axis tracker at different solar hours using the sun-sensor of the collector, the tracking error is being studied. In that study, the tracking error was estimated from the design of the sensor and was 0.93° at noon.

The tracking error has also been investigated in several recent studies. In the work of Díaz-Félix et al. [10], the absolute tracking error distribution of a heliostat was theoretically evaluated using Monte-Carlo simulations. Assuming several error sources on the heliostat position, the tracking errors were found to be up to 0.7°

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Nomenclature

α	solar absorptance (°)
α_0	solar absorptance at normal incidence (°)
α_c	inclination of the solar tracker (°)
α_s	solar altitude angle (°)
β_c	collector tilt (°)
ϕ_r	rim angle (°)
γ_c	concentrator azimuth angle (respect to south) (°)
γ_s	solar azimuth angle (respect to south) (°)
$\Delta\eta_{track}$	optical losses due to tracking error (%)
η_{opt}	optical efficiency of the collector (–)
θ_a	acceptance angle (°)
θ_d	defocus angle (°)
θ_i	incidence angle (°)
θ_L	longitudinal incidence angle (°)
θ_T	transversal incidence angle (°)
θ_{track}	angular tracking error (°)
ρ	solar reflectance (–)
σ	specular scattering mirrors (mrad) or standard deviation
τ	transmittance (–)
a	aperture width (m)
C	geometrical concentration ratio defined as the ratio of the aperture area to the absorber area (–)
CPV	concentrating photovoltaic
d_{abs}	absorber tube diameter (mm)
d_{glass}	glass tube diameter (mm)
EW	East–West
f	focal length (m)
G_{bT}	direct solar irradiance on the aperture plane (W/m^2)
G_{bn}	direct normal irradiance (W/m^2)
H_b	direct normal solar irradiation (MJ/m^2)
IAM	incidence angle modifier (–)
k	glass tube extinction coefficient (m^{-1})
K_b	incidence angle modifier relative to the direct incidence radiation (–)
$K_{b,sim}$	incidence angle modifier relative to the direct incidence radiation, obtained by simulation (–)
$K_{b,theor}$	incidence angle modifier relative to the direct incidence radiation, obtained by theoretical calculation (–)
L	collector length (m)
LED	Light Emitting Diode
NS	North–South
PTC	parabolic trough collector
u	wind speed (m/s)

with a circularly symmetric Gaussian distribution. In the study by Sun et al. [11], a beam characterization system was used to evaluate the tracking error of two heliostats from a central tower solar plant with an estimated accuracy of about 2% for the positioning angle measurement. Zheng et al. [12] analyzed the tracking error on an Linear Fresnel Reflectors collector, and the effect of different factors such as the reflectors positioning, the rotation axis position, the driver accuracy, the tracking software algorithm, the coordinates and the structure error.

In an earlier study, solar tracking using an inclinometer on a double-axis solar tracker was directly characterized [13]. Additionally, a testing procedure was defined to estimate the long-term tracking error due to the positioning of a small-sized solar tracking collector [14]. The maximum optical loss due to tracking was of 8.5%, but the average long-term optical loss calculated for one year was about 1%.

For a PTC, a single angle tracking, namely the elevation angle, must be examined in order to determine the solar tracker precision. Various methods are available to control the solar tracker elevation, such as optical device [15], artisanal shadow device [16], and angular sensor (encoder or inclinometer) [13].

There are different optical devices commercially available to characterize the tracking error. In 2009, Davis et al. designed a commercial device [17] with a high accuracy sensor using image processing to estimate the pointing error of double-axis solar trackers. In 2010, Minor and García also presented a solar tracking system based on image processing acquired by a webcam [15], which was able to measure the tracking error of a double-axis tracker with an accuracy of ±0.1°. In 2012, Missbach et al. [18] presented the results of a sun-sensor by Black Photon company, showing highly accurate measurements (standard deviation of 0.01%) on a double-axis tracking system for concentrating photovoltaic (CPV). But all these devices are applicable only for double-axis trackers and not for single-axis trackers.

The acceptance angle is commonly provided by the manufacturer of a solar concentrating system. This value is very useful to identify the requirements of the solar tracker mechanism, but does not provide information on the amount of optical losses in real operating conditions.

In this study, a single-axis solar tracker, used on a small-size PTC, is characterized. The paper is organized as follows: in Section 2 the components are presented; Section 3.1 describes the methodology to obtain the angular tracking error. In Section 3.2 the incidence angle modifier (IAM) is presented by a ray-tracing simulation. In Section 3.3 the optical losses due to the tracking errors are calculated using the angular errors estimated in Section 3.1 and the IAM curve obtained in Section 3.2. The results, presented in Section 4, show that during the testing period the 95th percentile tracking accuracy was 0.33° and the mean weighted optical losses leading to a reduction of the collector efficiency was 0.317%. Finally, the conclusions are compiled in Section 5.

2. Materials

2.1. Solar collector and solar tracker

The solar collector referred to in this study is a small-size PTC with a single-axis solar tracker, model PolyTrough 1800 manufactured by the company NEP Solar AG [19]. It had been tested in the SPF laboratory (Institut für Solartechnik [20]) according to the European standard EN 12975-2 [21], recently replaced by the International standard ISO 9806 [1].

In this solar tracker, the algorithm calculated the sun position at different times; hence it was classified as an active open-loop type actuator. However, no encoder was used, but there was a Hall sensor to detect the motor position. The precision of the tracker was supposed to be 0.025°.

This collector, shown in Fig. 1, was tested with an East–West (EW) orientation. The study by Larcher et al. [22] and the testing report from SPF [20] provide more details about the solar collector and the tests performed by SPF laboratory. A similar NEP collector PolyTrough 1200 with smaller aperture was tested by Miller et al. [23] at the Australian laboratory CSIRO according to different testing methodologies (standards [21,24] and Ref. [25]). In these studies, the thermal efficiency curves of different models were compared. However, the angle positioning errors of the tracking systems were not studied.