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Compensation of heliostat drift by seasonal sampling

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Abstract

Heliostat image drift is a common phenomenon in central receiver solar power plants. Several geometrical errors produce drift of the heliostat solar spot at receiver surface, increasing radiation spillage. A heuristic drift compensation method is proposed, based on a polynomial approximation to the drift trajectories. Results of the practical implementation of the proposed method for the control of 10 heliostats in a solar tower facility are presented. A substantial improvement of heliostat tracking is observed on the experimental tests. Because heliostat drift experimental monitoring is a time consuming task, a numerical analysis of the yearly behavior of the compensation method, based on simulations of heliostat drift, was carried out. In these simulations, the behavior of the daily RMS deviation of the concentrated solar spot centroid is evaluated for a whole year, as the polynomial correction is applied. The simulations serve also to test the effectiveness of the proposal polynomial method in a wider range of conditions. Thus, heliostats with a variety of primary error values are simulated. Random wind induced vibrations are introduced in the simulation to evaluate the effectiveness of the calibration method under noise conditions. It is found that a very effective calibration can be achieved with a few sampling events of the heliostat behavior during the year, taking only a few minutes. The RMS deviation can be reduced to values of the order of the wind induced noise level. The proposed polynomial compensation looks like a promising alternative to be implemented in heliostat fields.

Keywords: Central receiver technology; Solar power tower; Heliostat control; Solar tracking

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1. Introduction

Solar Tower Plants (STP), also known as Central Receiver Power Plants are a clean and feasible alternative to produce electricity with low greenhouse gases emissions. They have the great advantage of using existing generation systems, by converting thermal solar radiation to mechanical energy in a conventional steam cycle. Also, solar only around the clock operation has been demonstrated, thanks to heat storage. Their current limitation is a higher Levelized Energy Cost (LEC, total electricity cost including payback of initial investment and operating costs) ($ 0.19 USD/kW h) than the fossil fuel technologies ($ 0.07 USD/kW h) (NREL, 2013). One strategy to reduce the LEC for STP is increase the system efficiency, which can be done by rising the operating temperature and minimizing optical collection losses. The maximum conversion efficiency is limited to the ideal Carnot efficiency, which is defined by the temperature of the heat reservoir. Higher

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Nomenclature

F	fractional residual RMSD after compensation
$\hat{\mathbf{n}}$	heliostat normal unit vector
$\hat{\mathbf{r}}$	heliostat to receiver unit vector
$\hat{\mathbf{s}}$	solar position unit vector
$\hat{\mathbf{r}}_e$	reflected ray unit vector
$\hat{\mathbf{n}}_{e,o}$	deviated normal vector due to offset error
$\hat{\mathbf{n}}_e$	deviated normal vector due to lumped errors
$\mathbf{M}$	rotation matrix
RMSD_i	root mean square deviation for the i-th day, m

Greek symbols

θ	solar zenith angle, rad
ψ	solar azimuth angle, rad
β	heliostat slope angle, rad
γ	heliostat azimuth angle, rad
$\Delta\beta_e$	elevation offset, rad
$\Delta\gamma_e$	azimuth offset, rad
ε	heliostat tilt angle, rad
κ	heliostat tilt direction, rad

Subscripts

avg	average
comp	compensated
max	maximum

efficiency required increasing the working temperature and consequently the solar concentration ratio. The solar concentration system of a STP plant is formed by a group of sun-tracking mirrors called heliostats, which reflect the incident beam solar radiation onto the focal zone, the “receiver”, located at the top of the Tower (Behar et al., 2013); both of them, in conjunction with the storage system and the power generation stage, are the fundamental components of the system. The Heliostat field is a key component because it represents approximately 50% of the total plant investment (Kolb et al., 2011) and has a high impact on plant performance; its optical efficiency conditions the maximum achievable solar concentration ratio, the radiative flux distribution in the receiver, and the size and shape of the sun spot. There are estimation that around 10–20% of the heliostat field energy collection losses are caused by poor heliostat tracking due to hardware failures and geometrical errors (Jones and Stone, 1999). Small misalignments in the Heliostat angles of joust a few milliradians can produce considerable aiming errors due to the long distances travelled by the reflected beam before arriving to the target.

The most common heliostat tracking configuration is the altitude–azimuth open loop mode. The control system first calculates the sun’s relative position as function of the geographical coordinates of the heliostat field and the local time, then the direction of the heliostat normal is obtained using the computed sun vector and the coordinates of the heliostat and target centers, finally the heliostat control system moves the heliostat to the desired orientation, using encoders on the drive motors to verify its physical position. However, a series of fixed geometrical errors that affect the accuracy of the tracking system may arise. These errors are due to geometrical inaccuracies coming from different causes (Stone and Jones, 1999; Kribus et al., 2004): pedestal tilt, mirror canting errors, backlash, inaccuracy of the sun’s position model in the tracking software, encoder resolution and bias errors of the elevation and azimuth axes, non-orthogonally between the elevation and azimuth axes, errors in the surveyed heliostat location, and errors due to gravity loading and structure deformation.

Different strategies to compensate the heliostat pointing error have been proposed in the literature: Jones and Stone (1999) implemented an error-correcting model in the heliostat control system of “Solar Two” that eliminates time-variant tracking errors but the problem is that it requires many tracking accuracy measurements over a day to calculate the magnitude of each error source. Stone also developed a method of automatically aligning heliostats by comparing the actual sun beam centroid position on a target to a command reference position to determine the error in the sun beam centroid location (Stone, 1986). Berenguel et al. (2004) used an artificial vision technique and CCD cameras to calculate the deviation in the centroid and then they apply a low accuracy offset correction method, it was tested at the CESA-1 plant at the Plataforma Solar de Almeria. Kribus et al. (2004) developed closed loop control method to detect aiming errors and gradual drift errors; then an individual correction for each heliostats in the field is obtained after the dynamic measurement of the incident radiation on the receiver, detection of aiming errors, and feedback of a correction signal to the tracking algorithm. Moya and Ho (2011) performed a finite element analysis to evaluate the effects of the wind loading over the Heliostats structure with the objective to improve designs to mitigate the negative impacts on structural fatigue and optical performance. Guo et al. (2011) simulated the sun beam tracking error trace on the target plane for an azimuth–elevation tracking heliostat with fixed geometric errors. Recently, Zhang et al. (2012) developed an automated alignment method to correct pointing errors in which the location of the reflected spot on a target is measured repeatedly and linear regression is applied to estimate various geometrically-based physical misalignment parameters to facilitate pointing error correction. The latter methods required extensive characterization and evaluation over each heliostat, which is a time consuming task (Moya and Ho, 2011).