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Towards a satisfactory wind description for concentrated solar plants production assessment

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Abstract

In addition to the solar radiation, wind is other atmospheric parameter which affects the production of concentrated solar plants. The defence strategies, focused on preventing wind damages in collectors, force unproductive configurations in the solar field wasting part of the available resource. This brief note aims to define an efficient approach to estimate this wasted resource considering both the wind conditions and the defence strategy. In a first step, the wasted energy is assessed on four real-life cases considering three years of wind speed, wind gust and solar radiation data. Then, these results are compared with the ones obtained from four proposed approaches designed to test the level of wind description which is required to estimate the wasted resource successfully. Results show that accurate estimations can be obtained from a simple description of the annual mean daily profile of the wind in the emplacement.

Keywords: Wind; CSP; Resource assessment

1. Introduction

The increase of power and efficiency experimented by Concentrated Solar Plants (CSP) in recent years demonstrates their potential as renewable energy sources. The viability of these plants is primarily related to the solar irradiance of the selected emplacement. Thus, in preliminary design stages, only this atmospheric variable is considered for production assessment (Zhang et al., 2013; Desai et al., 2014; Rijanto et al., 2013; Malagueta et al., 2014). However, wind may strongly reduce the operative time of the collector field and consequently the exploited solar resource—thereby being other atmospheric parameter to have into account for an optimized plant design.

Studies concerning wind and CSP have been mainly focused on simulating loads in the collectors structure (Sun et al., 2014; Zemler et al., 2013; Mier-Torrecilla et al., 2014), since the solar collector field represent a high percentage of the investment in CSP (Sun et al., 2014). The design and selection of the collector structures requires the determination of the maximum wind loads expected in the emplacement.

However, wind also affects the plant operation as a result of the strategies to prevent structural damages. These strategies consist of bringing the collectors to a defence

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position (stow position) under certain wind conditions. Simply stated, the collectors are positioned offering the lowest opposition to the wind flow once the wind speed exceeds a specified limit (stow condition). During these periods the plant does not capture the solar energy and, consequently, a part of the available resource is wasted. Increasing this wind speed limit could represent a great investment in structures. On the contrary, a low defence limit could represent a significant waste of solar irradiance. Recently, Emes et al. analysed the cost of electricity from concentrating solar thermal power tower plants considering this factor (Emes et al., 2015). The cited work confirms the relevance of the wind conditions for power tower plants production, giving an excellent overview of all the affected aspects. The present brief note is focused on one of these aspects: the estimation of the wasted solar resource as a result of the wind conditions and the wind speed limit of the plant.

Eq. (1) gives a generalization of the power output of a CSP with stow condition (derived from the expression for power towers in Emes et al. (2015)):

$$P = DNI \cdot \psi_{CF} \cdot \eta(x_1, \ldots, x_n) \quad (1)$$

where DNI is the direct normal irradiance, ψ_{CF} is a parameter for capacity factor which is zero if wind speed limit is exceeded and the unity for other cases, and $\eta(x_1, \ldots, x_n)$ summarizes the efficiency of the plant as a function of different parameters $(x_1, \ldots, x_n)$ related the plant technology and characteristics.

Since ψ_{CF} is zero if the stow condition is fulfilled, the term $DNI \cdot \psi_{CF}$ models the DNI that can be actually exploited by the plant. The integration over time of this term computes the exploited solar resource as a part of the available resource. The other part is the wasted resource resulting from the stow condition. Note that this analysis can be performed avoiding considerations about technologies, efficiencies or processes of the plant. Thus it is applicable to all CSP with stow condition.

Based on this idea, this brief note is structured as follows. Section 2 deals with real series from four locations to analyse the effects of the stow condition in the wasted solar resource. In Section 3, the previous results are taken as reference to test four approaches focused on the estimation the wasted resource. Section 4 summarizes the conclusions of the test.

2. Effects of the defence strategy in the usable solar resource

Two different strategies are used in the preservation of the collectors field from wind damages. One evaluates the last 10-min mean speed value activating the defence protocol if this value overcomes a specified limit. The alternative strategy is similar but the activation limit is determined by the observed wind gusts instead of mean speed values.

The estimation of the wasted solar resource involves the detection of the periods in which collectors are unaligned/unproductive while reaching or being at the stow position. These periods are obviously associated to those times in which the speed limit is exceeded, and their duration is primarily related to the term of the wind risk. Hence, they can be determined by a simple analysis of the wind series as illustrated in Fig. 1. However, an accurate estimation of the wasted solar resource should consider the duration of the transitions between defence and optimized position which, besides an additional unproductive period, determine the time required by the solar field to be generative again once the wind risk has disappeared. These transitions depend, in each case, on the distance and course to (or from) the defence position, the maximum rotational speed of the collectors, the sun situation and the gradual unalignment during the maneouvre; being their individual effect difficult to evaluate. However, according to the authors' experience, this diversity of cases can be simplified considering 10 min as a representative time for these transitions. Thus, a resolution of, at least, 10 min is necessary to compute the operative time of the solar field. Hourly data could introduce important deviations in the estimation of the wasted resource, as stow periods cannot be accurately demarcated.

We choose a simple implementation of all the above said. The estimation of the wasted solar resource can be reduced to subtract the solar radiation received in those 10-min intervals in which the limit has been exceeded, adding and additional period of 10 min associated to the collectors re-alignment.

We have considered four different locations to illustrate how the defence strategy can reduce the usable solar resource: Écija, Almería and Tarifa in Andalusia (Spain) and Dora in New Mexico (USA). Some literature about CSP and solar potential of these areas can be found in tagkey200918 (2009), Martín and Martín (2013), Baharoon et al. (2015) and Madaeni et al. (2013). Solar radiation and wind data [2] from the period 2012–2014 (with the exception of Almería 2011–2013) have been compiled. These data allow to work with a resolution of ten minutes which is desirable to assess the impact of the defence strategy in the usable solar resource.

Table 1 shows relevant information about the studied locations: coordinates, irradiance, averaged wind speed (considering three years) and averaged gust factor.[3]

The primary analysis (see Table 1) shows that the chosen locations have a similar solar resource. However, Fig. 2 shows how the available solar resource can be strongly reduced depending on both the chosen defence strategy and the wind conditions of the emplacement. At Écija (Andalusia, Spain), the effects of the defence limit is minimum since the presence of the wind in the area is irrelevant. On the contrary, at Dora (New Mexico, USA), the wind conditions can produce great impact in the final

[2] Wind data are acquired at 10 m above ground level and includes mean speed and maximum gust observed in each 10-min interval.

[3] The averaged gust factor is calculated as the mean value of the ratios of the maximum gust to the mean wind speed registered in each 10-min interval.