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ScienceDirect

Energy Procedia 57 (2014) 291 – 300

Energy Procedia

2013 ISES Solar World Congress

Calculation of the blocking factor in heliostat fields

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Abstract

This paper presents a method for the calculation of the blocking losses of a heliostat, in terms of a blocking factor, arising due to neighboring heliostats in a heliostat field. The proposed method is general in the sense that it is valid for any type of heliostat array and orientation. In the method the individual blocking elements are projected on the plane of the heliostat under consideration. The heliostat plane is defined in the heliostat coordinate system. An analytical expression for the geometry of the projection is presented, and a numerical iterative technique is developed for the solution. The solution procedure involves the subdivision of the heliostat surface into a suitable grid. An overlap test is developed to determine whether a particular sub-area is blocked. In a straightforward manner, all blocked sub-areas are subtracted once from the overall heliostat area. A program was written by using MATLAB to test the method. In initial runs on lap-top (Intel(R) Core(TM) i3 M380 2.53 GHz), typical rectangular heliostats (9.8x10.7 meters) were subdivided into 25x25 grids. Results for the instantaneous blocking factors for each of 99 such neighboring heliostats, were obtained in an average run time of less than 3.5 seconds.

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Keywords: CRS; CSP; STE; Heliostat fields; Optical losses; Blocking factor.

1. Introduction

The performance of heliostat field is defined in terms of the optical efficiency. The optical efficiency is defined as the ratio of the net power intercepted by receiver to the direct insolation times the total mirror area. The optical losses include the cosine effect, shading and blocking losses, imperfect mirror reflectivity, atmospheric attenuation, and receiver spillage losses [1]. Some authors [1,2] think that while both shadowing and blocking increase if the heliostats are closer together, blocking has more pronounced effect on the layout of heliostat field.

Several researchers introduced methods to determine the usefulness efficiency of a heliostat surface. Biggs and Vittitoe [3] presented an idea based on projecting the outline of the aligned heliostats that

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doi:10.1016/j.egypro.2014.10.034

might block reflected light onto a unit sphere centered about the aim point. Blocked portions of any heliostat will appear in overlapped regions on this projection. The main objections to this procedure are that it may not be accurate in the case of multiple blocks and for late time. Also, that it is questionable whether the area ratio in the projection plane is equal to the actual area ratio by which the reflected flux is actually reduced.

Sassi [4] derived a combined analytical/discrete method for the calculation of the usefulness efficiency caused by a single heliostat. His idea was based on the projection of a blocking heliostat onto the plane of the heliostat under examination. He assumed that heliostat and projection had the same geometry and orientation, which is a simple case selected because it is more recurrent and because its mathematical development is simple. By no means it is a general case.

Collado and Turegano [2] derived an expression to predict the usefulness efficiency due to the two-shoulder heliostats in a radial azimuth staggered array. This expression is accurate only when the solar azimuth angle, heliostat azimuth angle and heliostat position azimuth angle are the same.

Elsayed *et al*. [5] developed an analytical expression for the usefulness efficiency of heliostat surfaces when considering all neighboring heliostats in any type of heliostat arrays. Their idea is based on determining the dimensions of the shadow on the plane of the heliostat under testing, and their main assumption is that both heliostats have approximately the same orientation. Again, this assumption is not valid for all cases.

Sànchez and Romero [6] calculated the Normalized Blocking using a simplified model. Among all the possible tracking positions it is assumed that the normal to the heliostat surface points at the aiming point since this represents the worst case. In addition, a grid of neighbors is created to calculate the effect at different positions. Although this approach has been useful for north field configurations, other approaches need to be formulated to generate in a better way surround fields, since the normal of the heliostats located south of the tower would never point at the receiver.

The method proposed in this paper overcomes the shortcomings of the cited procedures. The blocking losses are due to the interception of part of the reflected sunlight from heliostat by the backside of another heliostat. The blocking factor defined by Equation (1).

$$F_b = 1 - \frac{A_b}{A_{tr}} \tag{1}$$

where A_b is the blocked area of the heliostat surface and A_{tr} is the total reflecting area of the heliostat.

In this paper, a previous method to calculate shading factor [7] has been developed to pair with blocking factor calculation. As long as shadow is related to the incidence solar radiation, the blocking loss is related with the reflected sun beams. It may be possible to calculate a blocking factor by considering that the blocking heliostat acts as if it was a shading heliostat for rays traveling in a reverse direction to the reflected radiation. Starting from this idea, a vector has been imagined to apply on the reflected sun beam, but on the opposite direction. In other words, it is in the direction from the receiver to the Heliostat, forming a "*virtual shadow*" which represents the actual blocked area from the reflective Heliostat surface by neighboring Heliostat.

The effect of blocking is calculated by projecting the outline of the blocking heliostats onto the plane of the blocked heliostat using the heliostat coordinate system, O_2. The main assumptions are: an infinitesimal size of the sun, plane surfaces of the heliostats and no tracking errors. Hennet, as cited in

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