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Numerical Simulation of aiming point strategy method for small heliostat field for optimization of the receiver size

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ABSTRACT

In a solar central receiver system, solar radiation is concentrated on a tower mounted heat exchanger (receiver) by the use of mirrors called heliostats. These thermal systems are able to reach high temperatures and to obtain such temperatures; a high solar flux is required. This is achievable by aiming all of the heliostats at the center of the target. Due to this, high flux gradients over the receiver surface area and between the outer and inner surfaces of the receiver material can exist. These thermal gradients account for differences in temperatures on the receiver which results in thermal stresses leading to elastic and potentially plastic deformation of the receiver material. To eradicate the thermal stresses, the aim points of the heliostats can be managed such that the flux density distribution over the receiver aperture is decreased and homogenized. The primary objective of this paper is to develop an aiming strategy specifically for small experimental heliostat fields. There are different methods for eliminating the temperature gradient on the receiver plate like Aiming point Strategy, Field Modifications, Sizing the receiver. The SOLTRACE software, developed by NREL (National Renewable Energy Laboratory, United States) for the calculation of flux distribution maps has been implemented and used for simulating the solar field. The analysis is carried out for the flux distribution obtained by this simulation with aiming strategy and without aiming strategy. Based on the results obtained from the simulation with aiming point strategy in SOLTRACE software the homogenized flux image size will be optimized.

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I. INTRODUCTION

In a solar central receiver system, the receiver plays an important role of intercepting reflected solar radiation from the heliostat field and transferring thermal energy to the heat transfer fluid. The main purpose of central receivers is to intercept the solar rays concentrated by the heliostat field. Concentrate all heliostats at a single aim point on the receiver creates a Gaussian-like flux distribution with a very high flux density at the centre of the aperture and it is defined by the incident energy rate in [W/m^2] on the receiver surface from all directions. The main challenge associated with this process is the high temperature gradient at the receiver surface which may lead to generate the peak flux (Hot spot). Thermal gradients and high temperatures exist on the receiver due to the uneven distribution of flux and can lead to lower the receiver thermal efficiency, lifetime and consequently, degradation and failure of the receiver. Figure 1 represents the Flux distribution for a heliostat field with a single aim point in the centre of the receiver.

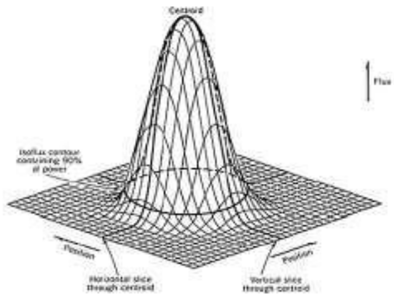


Figure 1: Flux distribution for a heliostat field with a single aim point in the centre of the receiver

The temperature distribution on the receiver surface depends on the four parameters like design of the receiver, thermophysical properties of the absorber, heat transfer fluid, and the heat flux distribution. Distribution of the heat flux on the receiver surface is one of the main parameter which is closely connected with the performance of the heliostat field. Therefore, it can be controlled by defining several aim points and adjusting the heliostats as per aiming points. Aiming strategies are used to distribute flux uniformly on the receiver while obtaining maximum power within the temperature and flux limitations. Various receiver designs exist each have distinctive limitations. Aiming strategies differ for each receiver due to their geometry and heliostat field design. The main purpose of aiming strategies is to have good receiver reliability, evenly distribute the flux and durability while keeping costs low and efficiency high with less thermal stress. A lot of research has been done pertaining to this context.

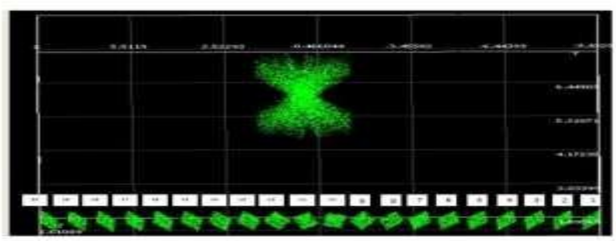
Grobler and Gauché [2], focused on the review of various aiming strategies and the corresponding receivers they pertain to. Salomé et al. [3], showed that aiming all the heliostats at the centre of the receiver causes a non-uniform high flux density on the aperture leading to reduced thermal efficiency and lifetime of the receiver. Belhomme et al .[4], showed that the above problem can be solved by introducing aiming strategies to distribute flux more evenly on the receiver while obtaining maximum power within the temperature and flux limitations. Augsburger [5], improved the flux optimisation by relating the positions of the aim points to the distance of each heliostat to the receiver. In this improved method, the closest heliostats are focused at the top and bottom aim points while further heliostats aim at the central aim points. Kelly [6], introduced a simple flux distribution profile in the study for evaluating six different central receiver plant designs. Here an even flux profile was created on the central 75% of each panel by moving each heliostat vertically up or down the panel.

García-Martí et al. [6], developed a closed loop automated system for the open cycle volumetric receiver where thin wire packages in the form of hexagonal cells make up the profile of the receiver. In this, initially, each heliostat is assigned to one of the five aim points in such a manner as to distribute the irradiance more evenly over the receiver aperture. The heliostats are relocated to other aim points such that the average temperature is within the set limits. An open loop control process that uses analytical flux prediction methods has been developed by Salomé et al .[7]. The main purpose of this method is to uniformly distribute the flux density on flat plate receivers within the limits of the system. An optimisation method was developed using the ant colony optimisation algorithm introduced by Dorigo (Ahlbrink et al.; Dorigo and Gambardella) [8, 9]. The optimisation method uses STRAL (Belhomme et al.)[10] ray tracing software instead of flux estimation. The optimization criterion for this method is to maximize the receiver output instead of the efficiency.

II. PROPOSED WORK

In central receiver technology radiation reflected from the heliostat field on the receiver surface forms a variation of flux density distribution. As it is already explained that a single point aiming strategy involves computing the sun vector and determining how the individual heliostats should move in order to reflect the concentrated solar light of each heliostat onto the centre of the receiver. This strategy does however have the possibility of causing an overheating of the receiver components and generate the hot spot. It can also produce thermal stresses due to thermal gradients which cause elastic and plastic deformation and lower the life of the receiver materials. So the objective is to flatten as much as possible the distribution of concentrated solar flux onto the receiver plate without increasing too much spillage.The heliostat systems which are mostly used in central receiver system all over the world are having the separate tracking system for each heliostat. Here the central receiver system on which the experimentation is to be carried out employed the ganged type of heliostat system. In ganged type of heliostat system number of heliostats are mounted on the single actuating rod in a row and tracked by a single motor. The heliostat system consists of heliostats of size 0.61m X 0.61m (2ft X 2ft) and the height of the center of heliostat is at 0.91m (3ft) from ground. There are 20 heliostats in a row and heliostat field consist of such 5 rows. Distance between two heliostats is taken as 0.91m (3ft). The distance of the centre of receiver is 6.096 m (20 ft) vertical from ground and 1.524 m (5ft) horizontal from 1st row of heliostats. The size of the receiver is taken as 2m X 2m.Here the aiming point strategy is initially applied for the 1st row of heliostats in the heliostat system. The SOLTRACE software is used for the analysis of aiming point strategy for the 1st row of 20 heliostats. The figure 2 shows the heliostat system with the heliostat numbers. Figure 3(a) shows the flux image on the receiver with single aim point of the 20 heliostats of 1st row, modelled in SOLTRACE software on 21st June at 1230hrs and Figure 3(b) represents the contour plot of flux plotted in MATLAB software. From this figures of flux image it is seen that the peak flux is at Centre of the receiver plate.

Figure 2. Heliostat System with heliostat numbers in 1st row.



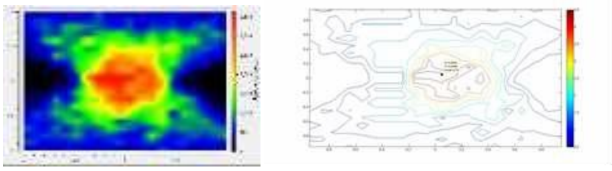
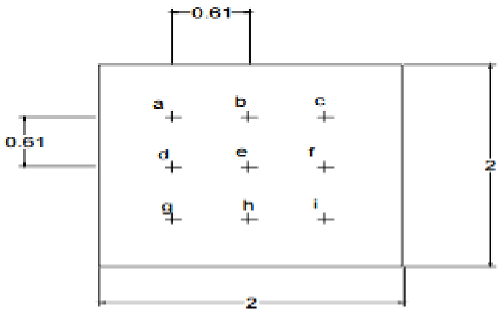


Figure 3. (a)Flux Image on the receiver of 20 heliostats (1st Row) (b) Flux contour plotted in MATLAB software

The Direct Normal radiation (DNI) value on 21st June is taken as 750W/m^2. The peak flux value when all the 20 heliostats from 1st row are aiming at a single point i.e. centre of the receiver plate is found to be 4740 W/m^2 and the average flux value as 1026 W/m^2 after tracing in SOLTRACE software. For this case the aiming point strategy is used. Nine aim points are defined on the receiver plate of size 2 m x 2 m as shown in figure 4. The distance between two consecutive aim points are taken as 0.61 m.

Figure 4. Nine aim points on 2m x 2m square receiver plate.



The concentrated flux density delivered by one heliostat depends on its position in the field related to the location of the target. Efficiency decreases with increasing distance to the target and to the Position of the sun in the sky the efficiency decreases with increasing incidence angle (cosine effect). Heliostats located at the edge of the field offer lower optical efficiency than those located in the centre of the field. In aiming strategy it consists of forcing low rated concentration heliostats (heliostats located at the edge of the field) to aim at aiming points located in the central area of the aperture.

Out of the 20 heliostats in the 1st row of the heliostat field the last for heliostats from east (heliostat nos. 1, 2, 3, 4) of the receiver and the last four heliostats from the west (heliostat nos. 17, 18, 19, 20) of the receiver are termed as the low rated heliostats and are aimed at the central aim point 'e' of the receiver. And the remaining heliostats called high rated heliostats (heliostat nos. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17) are allowed to aim at all the aiming points except centre 'e' defined in figure 4. The performance of the high rated heliostats is evaluated by the number of solar ray's hits on the aim points on the receiver plate in SOLTRACE software, when aiming them to all the aiming points except central aiming point. The aiming point is finalized for the respective heliostat where maximum number of solar ray's hits are obtained. Three different heliostat aiming strategy cases were studied using SOLTRACE. After analysis, the aim points for all the heliostats are finalized as given in the Table 1. For example heliostat numbers 15 and 16 gives highest solar rays hits on the receiver when their aiming points are fixed on 'a'.

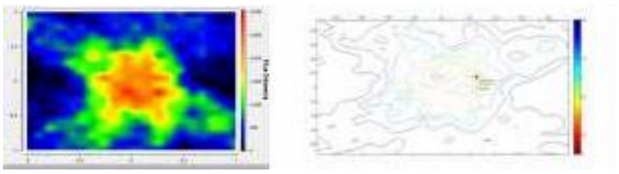
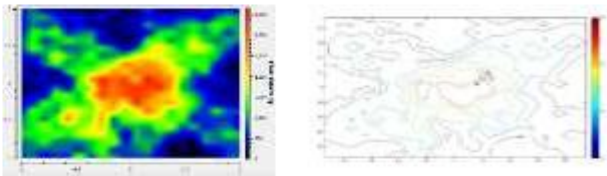


Table-1: Locations of the aim points for heliostats aiming strategy Case-1 on the receiver plate.

Aim Point	a	b	c	d	e	f	g	h	i
Heliostat Numbers	15,16	13	5,6	8	1,2,3,4,17,18 ,19,20	14	9,12	7,10	11

Now by using the above configurations of the heliostats and their finalized aim points, a new heliostat model is developed in SOLTRACE and after tracing the solar ray we get flux map and also a contour plotted using MATLAB as shown in following figure 5.



(a) (b)

Figure 5. (a) Flux Image on the receiver of 20 heliostats (1st Row) (b) Flux contour plotted in MATLAB software.

Further reduce the peak flux, some heliostat moved at different aiming point as mentioned in table 2 and table 3.

Table-2: Locations of the aim points for heliostats aiming strategy case-2 on the receiver plate.

Aim Point	a	b	c	d	e	f	g	h	i
Heliostat Numbers	16	12,9	5, 6	15	1, 2, 3, 4,7, 17, 18, 19, 20,	13	8	10,11	14

Table-3: Locations of the aim points for heliostats aiming strategy case-3 on the receiver plate.

Aim Point	a	b	c	d	e	f	g	h	i
Heliostat Numbers	16	12,13	6	15	1, 2, 3, 4, 17, 18, 19, 20,	7	8,9	10,11	14

Figure 6 and Figure 7 shows flux image and couture plot of these two heliostat aiming strategy (case-2 and case-3).

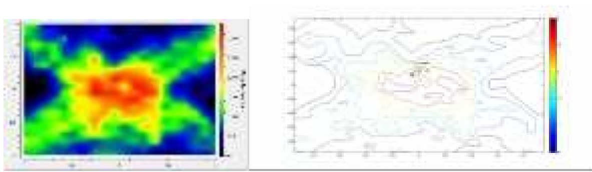


Figure 7. (a)Flux Image on the receiver of 20 heliostats (1st Row) (a) Flux contour plotted in MATLAB software

III. RESULT AND DISCUSSION

Comparing figures 3 and 5 we can observe that the flux gets spread on the receiver plate. The peak flux value gets lower from 4740 W/ $m^2$to 3670 W/ m^2 and the average value remains near about same. Similarly comparing the figure 3 with figure 6 and figure 7, peak flux reduce from 4740 W/m^2 to 4060W/m^2 and 4740 W/$m^2$to 3260W/m^2 respectively. From the above result it is clear that flux is distribute more evenly in case-3 of aiming strategy and less thermal gradient generate. In further studies the flux distribution on the receiver by 1st row of heliostat will be experimentally found out. By comparing SOLTRACE and experimental result for the 1st row, the aiming point strategy will be employed for the total heliostat field of 100 heliostats in SOLTRACE software, such that we should get the homogenized flux on the receiver plate and the receiver will be designed based on this results.

IV. CONCLUSION

The work in this paper presented an aiming strategy that can be used to obtain uniform heat flux density distribution on the receiver surface of a solar central receiver system. The flux density of heliostats was modelled using the SOLTRACE software. The receiver incident flux distribution is estimated by using Matlab software which allowing short computation times and programming interactivity. The analysis show that the receiver size of the aiming surface has a huge impact on the maximum flux density and density distribution on the receiver surface.

V. ACKNOWLEDGEMENT

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REFRENCES

[1] W.B.Stine and R.W.Harrigan, "Power from the Sun", John Wiley and Sons, Inc. 2001.

[2] Grobler, A. and Gauché, P. A review of aiming strategies for central receivers. Proceedings of the 2nd SASEC conference, January 2014, Port Elizabeth, South Africa.

[3]Salomé, A., Chhel, F., Flamant, G., Ferrière, A. and Thiery, F. Control of the flux distribution on a solar tower receiver using an optimized aiming point strategy: Application to THEMIS solar tower. Solar Energy, vol. 94, pp. 352–366 (2013).

[4]Belhomme, B., Pitz-Paal, R. and Schwarzbözl, P. Optimization of heliostat aim point selection for central receiver systems based on the ant colony optimization metaheuristic. Journal of Solar Energy Engineering, vol. 136, (2013).

[5]Augsburger, G. and Favrat, D. Modelling of the receiver transient flux distribution due to cloud passages on a solar tower thermal power plant. Solar Energy, vol. 87, pp. 42–52 (2013).

[6]Kelly, B.D. Advanced thermal storage for central receivers with supercritical coolants. Tech. Rep., Abengoa Solar Inc(2010).

[7]García-Martín, F., Berenguel, M., Valverde, A. and Camacho, E. Heuristic knowledge-based heliostat field control for the optimization of the temperature distribution in a volumetric receiver. Solar Energy, vol. 66, no. 5, pp. 355–369 (1999).

[8] Ahlbrink, N., Belhomme, B., Flesch, R., Quinto, D.M., Rong, A. and Schwarzbözl, P. STRAL: Fast ray tracing software with tool coupling capabilities for high- precision simulations of solar thermal power plants. Proceedings of the 16th SolarPACES conference, September 2010, Perpignan, France.

[9]Dorigo, M. and Gambardella, L.Ant colony system: a cooperative learning approach to the travelling salesman problem. Evolutionary Computation, IEEE, vol. 1, no. 1, pp. 53–66 (1997).