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Performance co-optimisation of a heliostat field and a cylindrical receiver

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In a tower-based CSP system, it is essential to understand the performance of the subsystems formed by the receiver and the heliostat field. In the literature, authors have mainly focused on the field optimisation [1] or the receiver optimisation [2] separately, and studies related to coupled optimisation are rare. Among these, Schmitz et al. [3] addressed a co-optimisation problem using a Genetic algorithm. The HFLCAL tool and ray-tracing software were compared in the optical simulation step, but no detailed receiver model was coupled with the optical simulations. Ramos et al. [4] optimized the field and the receiver using different optimisation algorithms. The optical efficiency was obtained from detailed optical models, and the receiver efficiency was calculated based on data fitting. Carrizosa et al. [5] proposed an alternating procedure for the co-optimisation. A greedy algorithm was used to generate a pattern-free field layout, but no detailed receiver thermal model was included in this study. Published studies do not include both detailed optical and receiver models; however, both models are important to obtain a reliable value for annual thermal output of the receiver, which acts as an essential criterion to judge the performance of this subsystem. In this study, different tools are integrated together to simulate the annual performance of the field and the receiver. A ray-tracing tool and an interpolation model are used to get the annual optical efficiency. The annual thermal output is obtained using a detailed receiver model together with a regression method. The co-optimisation method proposed in this study is used to optimise a system with a surround field and a cylindrical external receiver compatible with the Gen3 Liquid Pathway Project. The co-optimisation in this study is conducted with a fixed tower height and does not analyse cost contributions of the different components.

The flowchart of the co-optimisation method is shown in Figure 1. The input variables include three parameters from the Campo layout generation method [6] ($dsep$, $Nhel_1$, f_b), and the receiver dimension (H_{rec}, D_{rec}). Firstly, a large heliostat field layout is generated and the ray-tracing tool SOLSTICE [7] is used to calculate the optical efficiency of every heliostats. The annual optical simulation is simplified using the bi-cubic interpolation introduced by Grigoriev et al. [8]. The large field is then trimmed according to the annual optical efficiency of single heliostats to meet the required power collected by the receiver at the design point (Equinox solar noon). After the trimming process, the aiming strategy is adjusted to test if the receiver suffers from excessive flux. The modified deviation-based aiming method [9] is used to reduce the peak flux to an allowable limit. The annual performance of the trimmed field is then simulated to obtain the optical efficiency at each time point t ($\eta_{opt}(t)$).

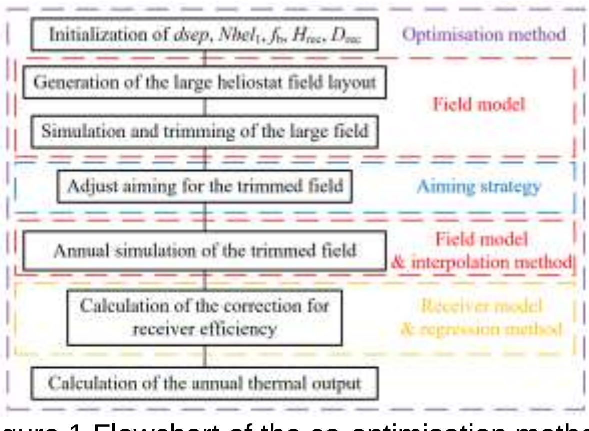

Figure 1 Flowchart of the co-optimisation method

The receiver performance is simulated using the receiver thermal model developed by Asselineau [10]. To obtain the annual receiver performance, a receiver efficiency look-up table (RELT) is generated based on the receiver incident power and the ambient temperature. A regression method is used to generate a correlation to calculate the receiver efficiency at each time point t ($\eta_{rec}(t)$). Then, the annual solar-to-thermal (total) efficiency ($\eta_{tot,ann}$) can be calculated and is chosen as the objective function of the optimisation:

$$\eta_{tot,ann} = \frac{\dot{Q}_{HTF,ann}}{GA_{ann}} = \frac{\sum_{i=1}^{365}\int_{sunrise}^{sunset} DNI(t)\eta_{opt}(t)\eta_{rec}(t)dt}{\sum_{i=1}^{365}\int_{sunrise}^{sunset} DNI(t)dt} \tag{1}$$

where DNI data is obtained from the typical meteorological year (TMY) data.

The Genetic algorithm (GA) as implemented in Dakota [11] is used for the optimisation. The simulations are executed in the supercomputer Gadi at the National Computational Infrastructure in Canberra, Australia. One optimisation case can be finished within 48 hours using 8 nodes in parallel, each with 192 GB of ram.

The co-optimisation method is used to optimise a system with a surround field and a cylindrical receiver. The tower height is fixed as 175 m. The width and height of the heliostats are both 12.2 m, and the slope error is 1.5 mrad. The optimisation results are shown in Figure 2 and Table 1. The optimum field is composed of 6886 heliostats. The height and diameter of the receiver are 25.1 m and 21.7 m, respectively. The thermal output of the receiver is 537 MWth at design point. The optimum annual total efficiency is 46.0%, and the optimum total efficiency at design point is 53.5%.

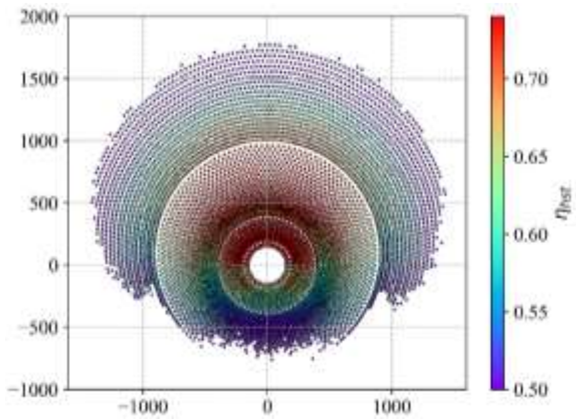

Figure 2 The optimum field layout

Parameters	Values
dsep	0.88
$Nhel_1$	17
f_b	0.83
H_{rec}	25.1 m
D_{rec}	21.7 m
Optical efficiency at design point	63.6%
Receiver efficiency at design point	84.1%
Total efficiency at design point	53.5%
Annual optical efficiency	57.0%
Annual receiver efficiency	80.7%
Annual total efficiency	46.0%
Thermal output at design point	537 MWth

Table 1 Results of the co-optimisation

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