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Optimisiation of Multi-aperture Falling Particle Cavity Receivers and Heliostat Fields

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Falling particle receivers require enclosure in a cavity to prevent disturbance of the curtain by ambient wind, however cavity receivers impose additional constraints on the heliostat field layout that may reduce the overall competitiveness compared to receiver technologies that allow for surround heliostat fields. As part of the ASTRI and Gen3 particle projects, CSIRO's Heliosim and Workspace software have been used to optimise the heliostat field layout and aperture configurations of commercial-scale particle systems. Both single and multi-aperture receiver configurations are considered. Multi-aperture configurations are calculated to provide improved annual efficiency for 500MW$_t$ systems where tower height and therefore rim angle is heavily restricted by cost, whilst single-aperture configurations are calculated to provide increased annual efficiency for 50MW$_t$ systems where proportionally taller towers are feasible.

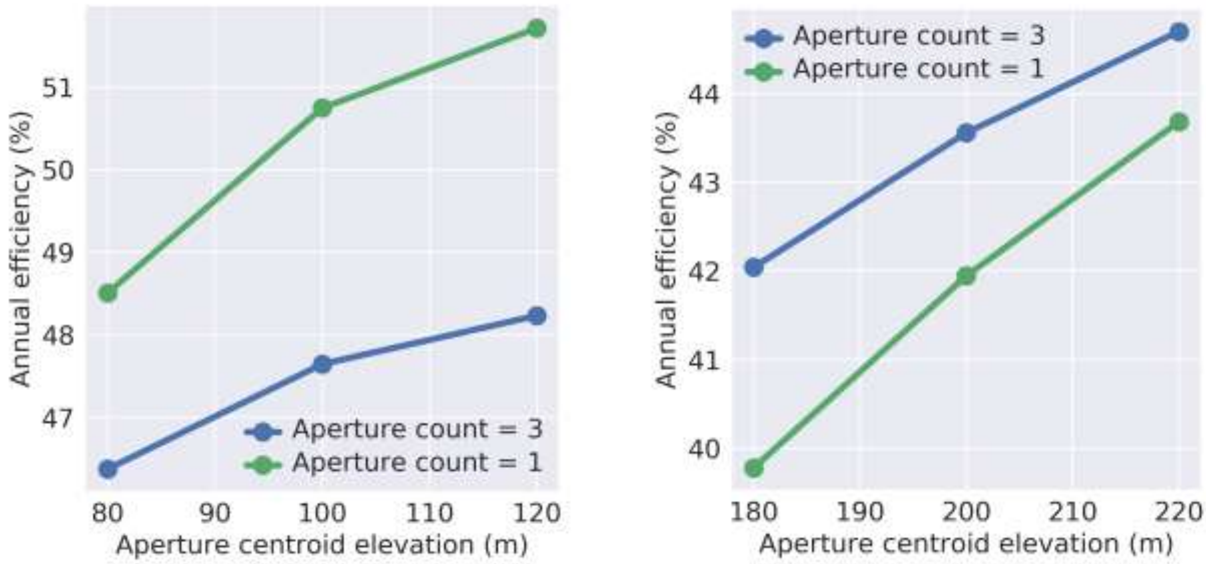
Problem formulation

The objective function to be maximised in the present work is the combined annual efficiency of the heliostat field and receiver sub-systems (i.e. thermal energy absorbed by the particles divided by solar energy incident on the heliostat field aperture area). The annual energies are calculated by temporal integration over the year with a constant 1 hour time step. The instantaneous optical efficiency of the heliostat field for any point in time throughout the year is calculated by linear interpolation from Monte Carlo ray tracing simulation results covering the annual hour angle and declination traversal of the sun. The instantaneous receiver efficiency is computed by a simple empirical model incorporating solar reflection, thermal radiation and convection losses. The DNI distribution throughout the year is obtained from typical meterological year (TMY) data.

The variable parameters for optimisation are the radii, elevation angle and azimuth angle for each receiver aperture, the design point thermal capacity for each receiver (expressed as the fraction of the polar receiver capacity), and the five parameters describing the radially staggered heliostat field layout. The fixed parameters are the site location, heliostat design, tower height, total design point thermal capacity and number of receivers. The total number of receivers must be odd, with one polar receiver and east-west symmetry preserved for the remaining receivers. For example, in the northern hemisphere, for a single north-facing receiver case there are seven variables to be optimised, whilst for a three receiver case with one north-facing receiver and two identical receivers on the east and west sides there are twelve variables. The tower height is a fixed parameter in the present work due to the absence of an LCOE model, which is in development. The objective function is formulated as a workflow in CSIRO's Workspace software, using specialised operations and datatypes for simulating CST systems provided by the Heliosim plugin (Potter et al., 2018). The Optimisation Loop operation (Potter et al., 2019) is then used to coordinate the optimisation iterations using a Nelder-Mead simplex algorithm.

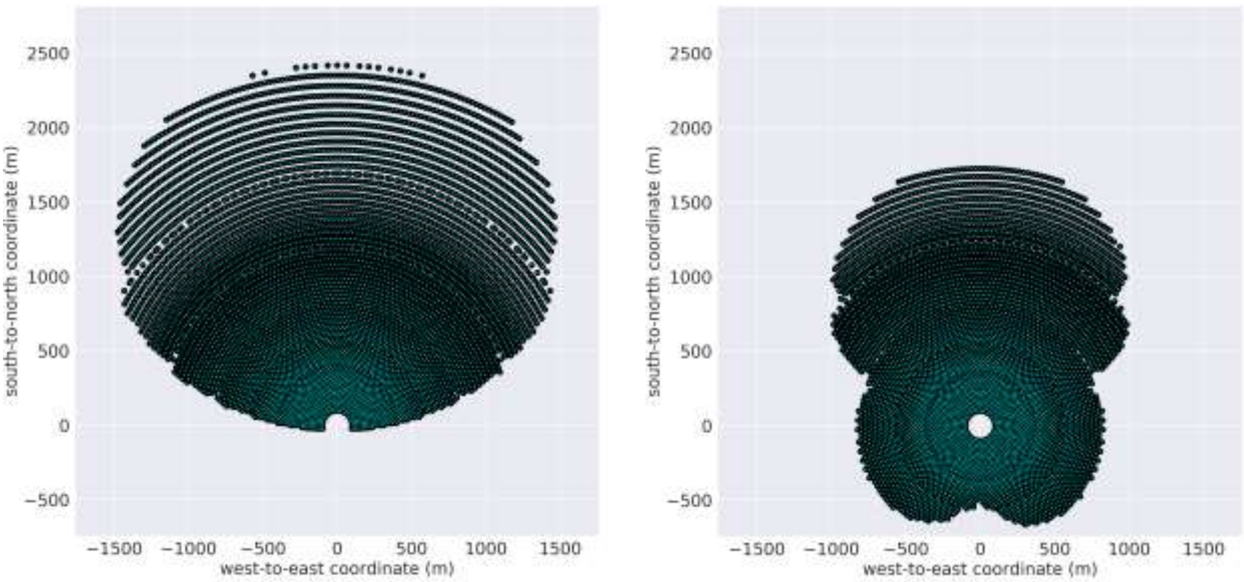
Results

In the present work 50 and 500MW$_t$ systems located in Dagget, CA, were considered. For each system, a parametric study over a limited range of tower heights and receiver counts were performed, Figure 1. For the range of optical tower heights and receiver counts considered, the 50MW$_t$ system was found to favour a single-receiver configuration, whilst the 500MWt favoured a three-receiver configuration. This is due to the optical tower height to heliostat field ratio (i.e. rim angle) being lower for the larger capacity system, thereby favouring a receiver configuration that allows a surround heliostat field (Figure 2b) instead of a polar field (Figure 2a). Future work will seek to incorporate system and cost modelling to optimise the systems based on LCOE.



(a) $50MW_t$ (b) $500MW_t$

Figure 1: Annual efficiency versus tower height for optimised systems.



(a) 1 aperture (b) 3 apertures

Figure 2: Heliostat field layouts for $500MW_t$ systems with tower heights of 200m.

References

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