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System level simulation in small scale molten salt CSP under mechanical constraints

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Recently, electricity costs in the Australian National Electric Market (NEM) have increased primarily due to the network costs associated with grid infrastructure upgrade and operation. The NEM supplies electricity predominantly to the populous coastal areas, but also to the remote inland areas with low population, where Direct Normal Irradiance (DNI) is significantly higher [1]. Decentralised generation through small-scale concentrated solar power (CSP) can mitigate network costs to these regions, if deployed close to the point of demand, because of their integrated storage which allows local demand to be matched to local supply. Small-scale CSP systems albeit with lower efficiency may provide value in this context, if storage capacity, tower, receiver, and solar field size are suitably adapted. Initiatives to develop down-scalable supercritical CO2 turbines are also relevant to this effort for CSP as with other thermal generation technologies [2]. Receivers in CSP plants, however, experience cyclic and non-homogeneous heat flux distribution, causing temperature gradients and thermal stresses. Therefore, it is important to keep solar flux distribution within mechanical safety limits. In this study, we identify an optimum combination of design parameters that maximizes the levelised cost of electricity (LCOE) of the systems, by adjusting the solar field size, tower height, receiver dimensions and storage capacity. Thermo-elastic stress calculations along with receiver life estimation from the ASME Boiler and Pressure Vessel Code, Division 1, subsection NH [3] are employed to consider the cost of periodic receiver replacement.

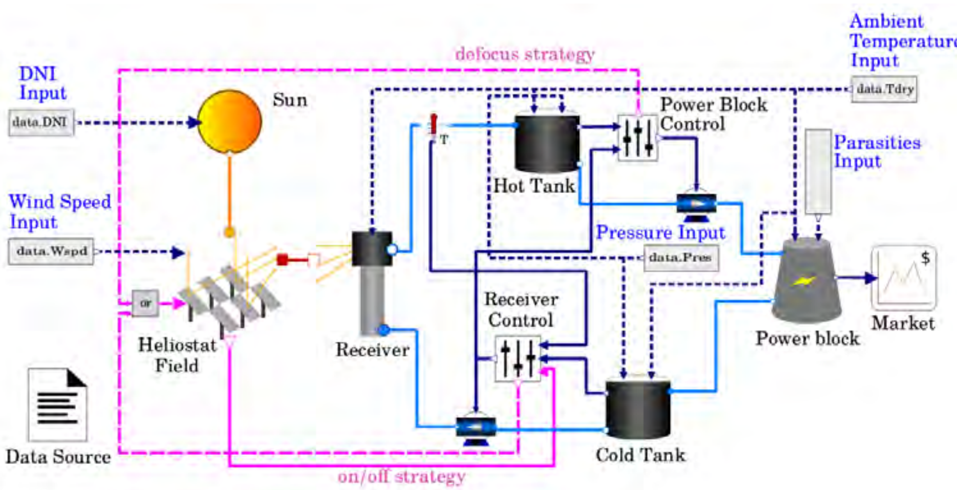

Figure 1. The ASTRI reference system, as shown in SolarTherm.

The molten salt, two-tank ASTRI reference case built in SolarTherm (Figure 1) [4] was used to simulate and analyse combinations of plant scale, storage hours (SH) and solar multiple (SM). Solar field, receiver dimensions, tower height, storage, and operation parameters were modified to scale down the plant. Power block efficiency at design point was adjusted for each plant size according to an empirical correlation [5]. Field layout and performance metrics were determined via SolarPILOT and exported to SolarTherm. Thermal stresses on the receiver pipes were determined via thermo-elastic analysis [6] from non-uniform heat flux distribution at design point (solar noon at spring equinox in Australia). A representative heat flux distribution along the receiver height is presented in Figure 2a for a 30 MW CSP plant size and a 2.2 solar multiple, where a maximum 800 kW/m2 heat flux is achieved. Time to rupture and number of cycles to failure were determined from the ASME Boiler and Pressure Vessel Code, Division 1, subsection NH [3], to compute the total creep-fatigue damage over the expected plant life. SAM default costing was adjusted to determine capital expenditures, and operation and maintenance costs by introducing an empirical latticework steel cost function for tower heights below 120 m [7]. All costs were scaled to 2018-year basis via the Chemical Engineering Plant Cost Index. Verification was conducted by comparing results with a model in the System Advisor Model (SAM) software. Differences between SAM and SolarTherm in the annual receiver output and net electrical power output were found to be -5.1% and -2.8%, respectively.

Figure 2b show the result of the thermo-elastic analysis, where maximum Von Mises stress is presented as a function of CSP size and solar multiple. The increase in solar multiple leads to a reduction of thermal stresses in all plant sizes, but also to higher temperatures on the receiver external surface, which increases creep-fatigue damage and reduces the receiver life. Figure 2c illustrates the effect of solar multiple on the total damage for a 30 MW CSP plant. Solar multiples of 1.4 and 2.2 lead to total damages below the safety limits, while solar multiples of 3.0 and 3.4 exhibits total damages above the safety limits, requiring periodic receiver replacement and higher maintenance costs.

In conclusion, the use of this model allows ensuring the optimal choice between a low-cost receiver with cheap materials and frequently replacements, and expensive receivers with high-resistance materials with no replacement.

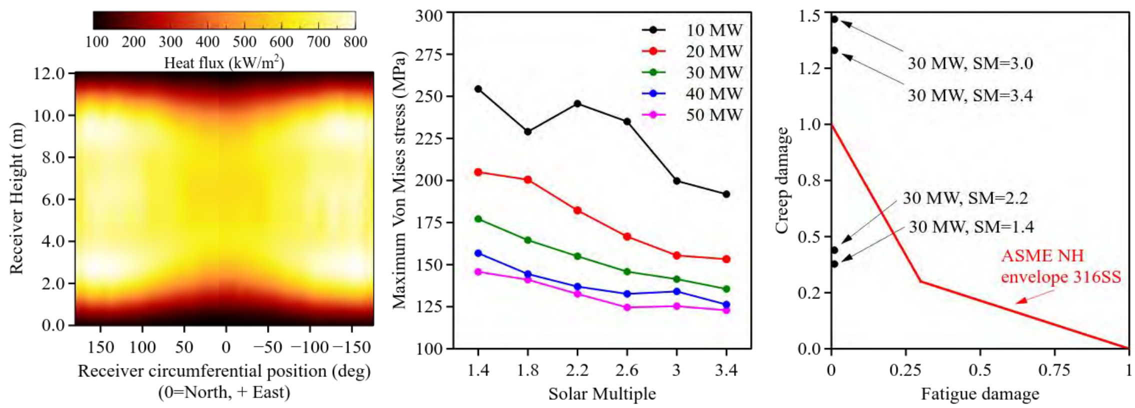

Figure 2. a) Representative receiver flux map at design point (30 MW, SM=2.2), b) Maximum Von Mises stress as a function of CSP size and solar multiple, c) Total creep-fatigue damage from non-uniform heat flux in a 30 MW CSP plant and four solar multiples (SM).

References

[1] Australian Renewable Energy Agency (2018). Technical Report: Lessons from the fringes: Australian fringe-of-grid projects in ARENA's portfolio.

[2] J. Holland and Associate, (2019). Technical Report: Australian concentrating solar thermal roadmap, Australian Renewable Energy National Agency.

[3] ASME Boiler & Code, P. V. (2007). Section III Division 1. Subsection NH, ASME International, New York.

[4] P. Scott, A. de la Calle, J. Hinkley, J. Pye, AIP Conference Proceedings, 1850 (2017).

[5] M. Meybodi and A. Beath, Renewable energy, 93 (2016) 510–524.

[6] W. Logie, J. Pye, J. Coventry, Solar Energy, 15 (2018) 368-379.

[7] B. Kistler, Sandia National Laboratories, Sandia Report No. SAND86-8018 (1986).