Assessment of high temperature hybrid CPV-CSP receiver and solar plant performances by numerical simulation

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Combining Photovoltaics or Concentrating Photovoltaics (CPV) systems and Concentrated Solar Power (CSP) in single compact hybrid power plants has been proposed for several years as an interesting route to lower solar electricity costs by maximizing solar energy conversion efficiency. Several concepts have been proposed [1] including high temperature PV topping based on a dual-receiver (placed at the top of a solar tower) allowing both direct production of PV electricity and collection of high temperature heat (to be converted in electricity via a thermodynamic cycle). A few studies have demonstrated the ability of III-V solar cells to operate at temperature up to 400°C [2]; however, due to the still uncertain reliability of high temperature cells and the intrinsic technical complexity of the concept, high temperature hybrid power plants have never been built yet.

Theoretical assessments of high temperature CPV-CSP plant performances conducted to date have been based on major simplifications, without serious consideration of neither the receiver design nor real operating technical constraints. In this work, we perform a multi-physics modeling of a high temperature CPV-CSP plant consisting of a heliostat field typically concentrating 5 MW of solar radiation on a 2x4 m dual receiver comprising 80000 interconnected III-V solar cells placed at the top of a solar tower. The heat released by the solar cells is collected by a heat transfer fluid powering a thermodynamic cycle to produce electricity in addition to the direct power generation by the cells. Compared to previous analyses of such systems (e.g. in [3]), we go further in the design of the dual receiver as well as in the modeling of the different parts of the system in order to perform more realistic simulations and assess the performances of the hybrid plant under several technical constraints. In particular, we scrutinize the influence of the interconnections between the solar cells protected by bypass diodes, the influence of the solar flux uniformity over the cells, that of the heat transfer fluid characteristics, etc. in order to identify the main factors responsible for energy losses and select the best operating conditions.

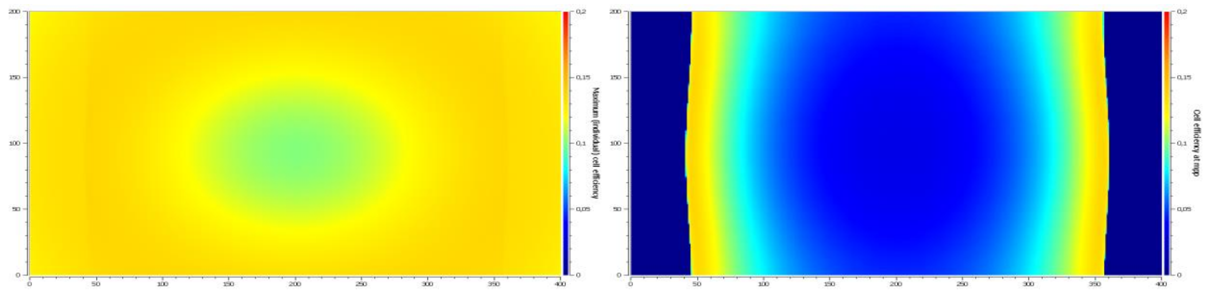

Fig 1: simulation of the conversion efficiency of the CPV-CSP receiver made up of 200 x 400 GaAs cells under highly non-uniform flux conditions. Left: maximal efficiency achievable under local temperature and concentration conditions, without considering any current mismatch between cells (ideal but unrealistic). Right: efficiency distribution for a series/parallel connection scheme consisting of 200 strings connected in parallel, each string consisting of 400 series-connected cells with bypass diodes.

[1] Xing Ju, Chao Xu, Yangqing Hu, Xue Han, Gaosheng Wei, and Xiaoze Du. A review on the development of photovoltaic/concentrated solar power (pv-csp) hybrid systems. Solar Energy Materials and Solar Cells, 161 (2017) 305–327.

[2] E. E. Perl, J. Simon, J. F. Geisz, M. L. Lee, D. J. Friedman, M. A. Steiner, Measurements and modeling of III-V solar cells at high temperatures up to 400°C, IEEE Journal of Photovoltaics 6 (5) (2016) 1345–1352.

[3] Dounia Ziyati, Alain Dollet, Gilles Flamant, Yann Volut, Emmanuel Guillot, Alexis Vossier. A multiphysics model of large-scale compact PV–CSP hybrid plants. Applied Energy, 288 (2021) 116644.