Effects of solar flux uniformity on the performance of a high temperature hybrid CPV-CSP receiver

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We have performed multi-physics simulations of a dense array receiver that is the most critical element of a large compact high temperature hybrid CPV-CSP plant. The receiver directly produces electricity from dual-junction PV cells while collecting the high temperature heat released to power a downstream thermodynamic cycle. As compared to conventional dense array CPV systems, the compact high temperature hybrid plant uses a heliostat field to focus the solar radiation on the receiver located at the top of a tower, from which heat is extracted and transported using a specific heat transfer fluid (HTF).

It is well-know that non-uniform distribution of solar radiation over a PV converter (module or panel) is detrimental to its overall performance, inducing current and voltage mismatches, the amplitude of which is also enhanced by the temperature inhomogeneity resulting from the non-homogeneous illumination. This issue is familiar to Concentrating PV systems, especially those based on a dense array PV receiver. Several strategies can be implemented to mitigate the negative impact of these non-uniformities on the overall PV efficiency, which usually consists in using secondary optics to improve solar flux uniformity, appropriate cell interconnection schemes mostly based on bypass diodes (BPD) to avoid current mismatch [1], and cooling devices tailored to minimize temperature gradients.

In the present case, additional difficulties arise from the huge number of interconnected solar cells (80,000 1cm x 1cm cells in a single receiver), the high operating cell temperature range (300-400°C) and the specific lower and upper temperature bounds for each HTF considered. Our simulations have evidenced several interesting but sometimes counterintuitive behaviours, in particular: i) the highest PV efficiency can be achieved with a highly non-uniform illumination of the receiver using an appropriate cell/module interconnection scheme; ii) the most efficient HTF may lead to the highest cell temperature, iii) blocking diodes may favor negative current flow in solar cells instead of protecting them.
Several simulation examples are presented to illustrate these behaviors, which are subsequently analyzed and interpreted. As an example, figure 1 shows the power produced by individual cells in similar conditions (flux distribution, inlet fluid temperature & HTF flow rate) but using different interconnection schemes.

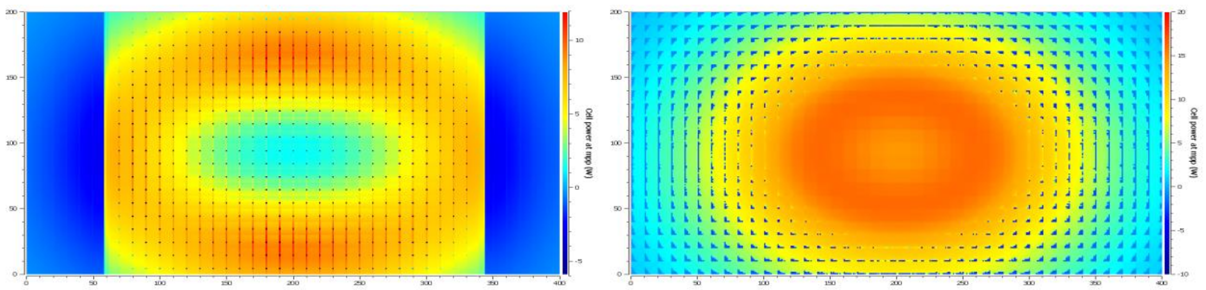

Figure 1: Simulation of the net power produced by the individual (GaInP-GaAs) cells under highly non-uniform flux conditions. Modules are composed of 10x10 interconnected cells protected by BPD.

Left: Parallel/Series interconnection scheme for modules (each module has a blocking diode) as well as for cells in modules. Power is consumed rather than produced in the left and right regions of the domain (voltage is <0 in these areas). Power is also consumed by the cells at the vicinity of the blocking diodes (cell current is <0). The overall PV efficiency is 6.51%

Right: All cells in modules (without blocking diodes) are interconnected in series and all modules are connected in parallel. Regions where BPD are activated are more widely distributed in the receiver. Overall PV efficiency is 17.34%.

[1] F. Belhachat, C. Larbes "Modeling, analysis and comparison of solar photovoltaic array configurations under partial shading conditions". Solar Energy 120 (2015) 399–418