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next-CSP

High Temperature concentrated solar thermal power plant with particle receiver and direct thermal storage

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Deliverable *D6.1*

WP6 – Assessment of the highly efficient thermodynamic cycles that can be combined with the high temperature solar loop

Deliverable D6.1 Report on solar power plant design methodology

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Foreword

This report (D6.1) describes the proposed methodology for solar power plant optimization that will be later used for solar plant modelling of the project NEXT-CSP.

The report has been prepared by IMDEA Energy (lead partner) and attaches EDF solving methodology contribution.

1 Introduction

The installation and use of renewable energy sources for electricity production is gaining in importance due to stringent environmental standards seeking to reduce pollutant emissions and fossil fuel dependence. In this context, concentrating solar thermal technologies (CST) are considered to be one of the most promising means for electricity production in coming decades [1]. Concentrating solar power (CSP) has shown many advantages compared to other intermittent renewable electricity sources such as wind and photovoltaics. Amongst the main advantages; solar thermal electricity is reliable, flexible and when integrated with thermal energy storage (TES) systems is not limited to operating only when the sun is shining [2]. In addition, when coupled with dry-cooling, the water requirement of CSP technologies is limited [3]. However, cost reductions achieved by competing technologies are forcing CSP developers to move a step further seeking for cost reductions due a highly competitive market and the lack of tariffs that correctly value the dispatchability of CSP [4]. This could be achieved through economies of scale [5,6], by implementing new technological developments leading to higher solar-to-electricity efficiencies and by optimizing operation and maintenance strategies on CSP plants [7,8].

One alternative to increase the efficiency of the CSP plant involves using a new heat transfer fluid (HTF) capable of operating at higher temperatures than current direct steam generation or molten salt technologies. One interesting option is the use of a dense gas-particle suspension (or DPS), consisting of very small particles which can be easily fluidized at low gas speeds. The fraction of particles within the suspension is high (up to around 40% by volume [9]) resulting in a fluid with a high density (above 1,000 kg/m^3) and a significant improvement in heat transfer between the solar collector and the HTF (above 500 W/m^{2}K [10]). If ceramic particles are considered, extremely high temperatures can be achieved (above 1,000 °C [11]). Furthermore, due to the high density of particles and the ease of separating them from the entraining gas flow, TES can be easily implemented through simple bulk storage of hot particles. As the particles remain solid, there is no lower temperature limit (as in the case for molten salts), allowing the TES units to operate across a wider temperature range.

With a view to establishing utility scale power plant designs based around this novel HTF, a **unified and consistent methodology must be established to design, analyze and optimize power plant components**. The central receiver is based on a fluidized bed of particles (type A particles according to Geldart classification [12]) moved upwards through a tubular receiver using air as the entraining gas. Experiments performed under CSP2 project [13] proved the feasibility of this concept for solar receiver applications [10]. Temperatures up to 650 °C for receiver particles were achieved what is opening the possibility for connecting this type of solar receiver to a wide selection of power cycles [14].

In this report, methodology proposed for the design and optimization of a CSP plant using DPS as both the HTF and TES medium is presented. For validation purposes, IMDEA Energy solving methodology has been aplied to 57 MW$_{th}$ particles receiver coupled to subcritical Rankine cycle and compared to the results obtained using Thermoflex commercial software and power plant design expertise from EDF.

7 Conclusions

In this report, optimization methodology for central receiver solar power plant has been described and applied to a CSP plant based on dense particle suspension as heat transfer fluid and storage medium. Boundary conditions have been set from project requirements while the rest have been optimized for energy harvesting and efficiency maximizing using methodology proposed into this work. Particles solar central receiver using dense particle suspension was designed and optimized following an iterative solving procedure and considering design restrictions and power plant boundary conditions.

Two thermal power scenarios were considered for power plant components optimization, for medium and large size solar plants. Heliostat field was designed following an iterative solving procedure to match receiver operation requirements. Storage tanks were designed in order to accomplish 6 hours of storage capacity and solar multiple of 2. A high performance 5 stages reheated subcritical Rankine cycle was optimized for efficiency maximizing working coupled to solar plant using fluidized bed heat exchanger technologies.

Mathematical models were encoded into MATLAB subroutines in order to have a powerful and flexible platform ready to be used for multiple power block configurations or to perform sensitivity studies. Solar power plant performance over a whole year was also analyzed using TRNSYS platform and proposing a series of control strategies to deal with intermittent weather conditions and power block start-ups in order to assure power block operation under nominal-plate conditions. Power plant working conditions for steady and annual operation agreed with standard practice results from similar plant demonstrators. Optimized solar power plants provided 17% sun-to-electricity efficiency with 55% capacity factor.

In parallel, Thermoflow’s Steam-PRO is used to design an optimized Rankine steam cycle that meets the same ambient conditions and the main thermodynamic assumptions (such as main and reheat steam pressures and temperatures, turbine efficiencies, number of bleeds, deaerator pressure, etc.). That optimized Steam-PRO model can be later integrated as a black box into Thermoflex in order to model the whole power block comprising the thermodynamic cycle and the DPS-HX (i.e. the particle-to-water/steam exchanger train).