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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 *D6.3*

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

Deliverable D6.3 Report about high efficiency solar power plant performance

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Foreword

This report (D6.3) presents the sizing for the solar plant (of which flow-sheeting scheme was proposed on deliverable D6.2) and the corresponding thermal integration at the design point. Task 6.3 is entitled *Operation modes and dynamic modelling of solar power plant*, which addresses the performance analysis of the optimized Next-CSP solar plant concept coupled to Combined Cycle power block.

This report has been prepared by IMDEA Energy (lead partner of WP6) based on a thermodynamic approach and does not completely account for all the technical issues and engineering solutions that are currently under discussion in WP7 by the time of this report is submitted (e.g. solar field layout and sizing; heat exchangers; outlet temperature of particles or hot particles transport). Updated information on design and up-scaling stemming from WP7 will be integrated accordingly during the elaboration of D6.4.

Introduction and Objectives

It is widely known that technological, scientific and social progress together with the general improvement of the quality of life are tightly bounded to an extensive energy consumption. In this context, primary energy demand keeps growing rapidly and the forecast from the World Bank is showing a drastic increase in the global demand for energy supply. Experts are warning that projections on electricity demand will increase by roughly 100% from 2000 to 2050 [1,2].

Renewable energy becomes crucial to satisfy the ever-growing electricity demand and at the same time reducing the environmental impact and the dependency on fossil fuels. Despite the maturity of photovoltaics and wind technologies, their capacity is not always available and the electricity generation becomes highly dependent on the time of the day and the weather. These fluctuations in generation become a challenge to the grid and it is mandatory increasing the presence of renewable energy sources with flexible dispatch. In particular, *Concentrating Solar Power or CSP* is one of the most suitable candidates for flexible electricity dispatch since it allows for massive and non-expensive thermal energy storage (TES). Wise design of TES systems and plant operation strategies allow for decoupling energy harvesting of the solar field from the electricity production on the power block. This issue improves grid stability and allows for power plant operation extension even after sunset.

Lot of experience has been gained over the last few decades about the operation of commercial CSP plants, mainly using parabolic trough technology and more recently molten-salts towers. Despite good performance of both technologies, figures are showing that CSP technologies are still expensive in terms of levelized cost of electricity (LCOE) compared to photovoltaics and wind. Based on thermal nature of CSP technology, increasing the working temperature of the power block would boost power cycle efficiency. Nevertheless, the main constraint on CSP plant efficiency is imposed by maximum operating temperature of the heat transfer fluid (HTF). For solar tower plants, molten salts are used as HTF and the working temperature is currently limited to approx. 565 ºC on the receiver and in turn imposes the steam Rankine cycle as the most efficient solution for the power block.

In Next-CSP concept, dense particle suspension (DPS) is used as HTF for the receiver and solid particles as storage medium instead of commercial molten salt. This enables to reach working temperatures above 800 ºC [3] which in turns will lead to higher energy density of the TES system and implement higher-efficiency thermodynamic cycles..

In this report, results are presented for nominal operation of the optimized Next-CSP solar power plant. The following components have been sized:

- Power block
- Particles heat exchanger
- Storage tanks
- Particles transportation system
- Solar receiver
- Solar field

Conclusions

Attending to Next-CSP project targets and KPIs, it is needed to design each component in a way to maximize its efficiency. This will assure high efficiency of the global CSP-plant.

- Receiver design efficiency > 80 %
- Power block design efficiency (Combined Cycle) ~ 50 %
- Fluidized bed heat exchanger design efficiency > 90 %

As it was observed on summary table, high efficiency criteria for DPS-HX network was difficult to accomplish for intermediate and low pressure heat exchangers. Tight boundary conditions such as reduced pressure drop of air inside DPS-HX tubes, low pressure of air inside tubes for IP and LP DPS-HX and maximizing the temperature drop of particles is leading to complex design of heat exchanger resulting into nominal design efficiency below 90% on average.

In order to guarantee highest efficiency of solar receiver, cavity design is required and therefore North-oriented solar field should be considered as the only practical solution. Maximum thermal power that can reach solar receiver is determined by the quality of the reflected spot from the last row heliostats and receiver aperture size. Based on aperture size and North field requirements, it was determined by sbp partner that the maximum thermal power that could reach the receiver would be around 68 MW_{th} before considering thermal losses on the receiver. Cavity receiver efficiency depends on several working parameters such as internal heat transfer coefficient (h) between receiver tubes and particles. At this stage given value from previous experiments has been considered. Receiver efficiency will increase as long as receiver tubes internal geometry is being optimized through CFD and experiments that are undergoing at this stage.

Despite typically-high efficiency of Combined Cycle power blocks, target of exceeding 50% efficiency was not achieved due to the low TIT (780 ºC). Despite double-reheating configuration, maximum net efficiency of 48.6% was observed for power block. Increasing TIT will contribute to improve power cycle efficiency above 50% as it was expected.

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