Towards a more efficient generation of central tower hybrid thermosolar gas turbine power plants

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1. Introduction

During the last years a significant R&D&i effort to develop energy production technologies capable to provide clean and efficient generation on one side, and reliable, non-intermittent, and predictable on the other is being done. In thermosolar power plants with a central tower receiver a working fluid runs a thermodynamic heat engine as a Rankine or Brayton one (or a combination of both) [1]. In these plants it is feasible to include a combustion chamber in series with the solar receiver in such a way that during low irradiance periods due to meteorological conditions or during the nights, the combustion chamber can provide the heat input required to keep approximately constant the turbine inlet temperature. And so, the plant power output. These plants are not completely carbon free, because of the combustion of a fossil fuel (usually natural gas) but produce constant, reliable, and predictable electric power to the grid with reduced fuel consumption and emissions.

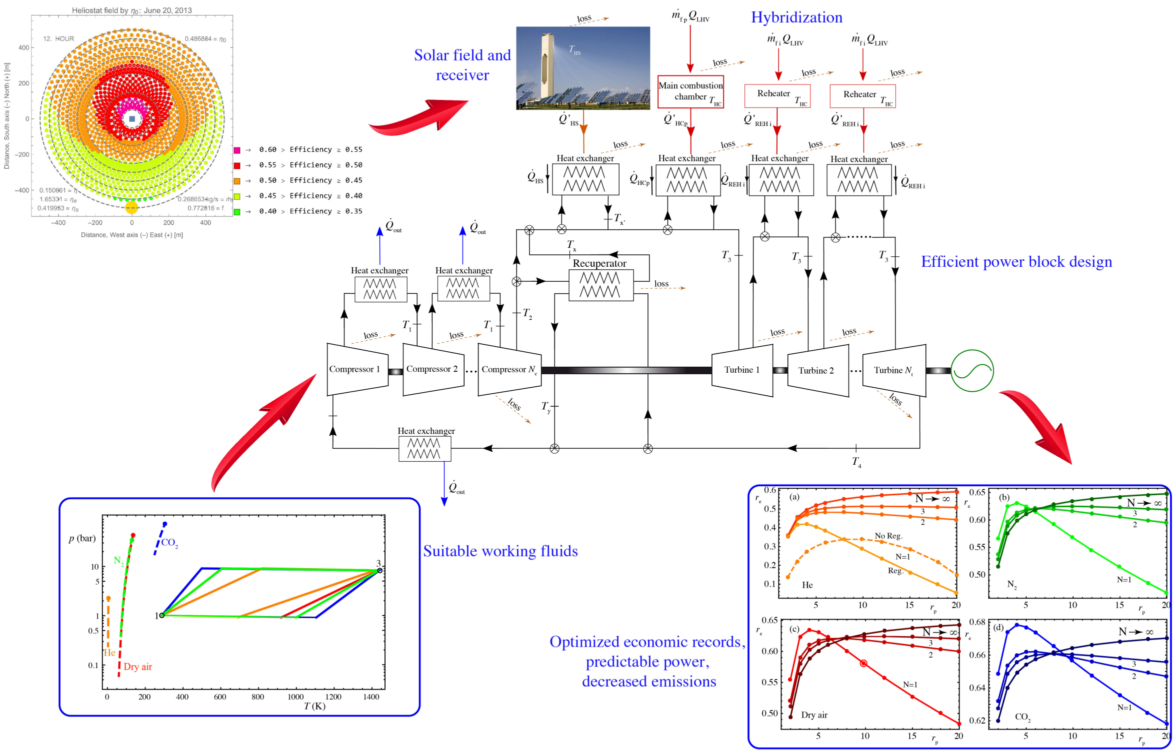

Fig. 1: Graphical scheme of the integrated model proposed in the work.

2. Overall plant model and numerical simulation

Several projects during the last 10 years allowed for building prototype and pre-commercial scale plants [2]. All of them coincide in the feasibility of this kind of installations and the mentioned advantages. Particularly, those ones working (from the thermodynamic viewpoint) under Brayton-like cycles have additional benefits: very reduced water consumption, high efficiency rates, not too complex control systems, flexibility, scalability, and reliability [3]. Nevertheless, another agreement among researchers and developing companies is that improvements are still necessary in order to produce energy at competitive prices, and so, to develop plants at commercial scales. There are several work lines to investigate: solar field and receivers design and materials, appropriate heat exchangers for very high temperatures, efficient Brayton cycle layouts, improved working fluids, and others [4].

In this communication we present a novel model for the pre-design of hybrid thermosolar Brayton plants developed during the last times by our research group. The plant is described as a whole allowing to predict overall performance. It is considered as composed by three subsystems: solar field and receiver, combustion chamber, and power block, and several heat exchangers between them [5]. Overall efficiency is obtained as a combination of subsystems efficiencies. Solar field efficiency is computed in detail for any location and any meteorological conditions. Most important losses are considered, including shadowing, blocking, spillage, atmospheric attenuation, and so on. A simplified model is taken for the thermal losses in the receiver, including radiation losses. For the power block a detailed thermodynamic model based on an irreversible Brayton cycle is assumed. Multi-stage compression and expansion and regeneration are included in the model. The temperature dependence of the specific heats of the working fluid is incorporated, and so, the performance associated to different fluids can be estimated [6]. All these ingredients allow for obtaining precise estimations of plant performance at off-design conditions as diary power and efficiency curves, consumption, emissions, and fuel conversion efficiency, in terms of a relatively reduced number of parameters with clear physical meaning, avoiding complex and over-detailed engineering computations. Annual averages are also susceptible to be computed for real meteorological conditions. And so, sensitivity analysis and optimization suggestions can be performed in the framework of the model.

In this contribution it will be shown the comparison of model predictions both with experimental records of a similar size heliostat field (data are taken from *Gemasolar Plant*, located at Seville, Spain) and with commercial software (*Thermoflex*). Four working gases are analyzed at subcritical conditions: air, nitrogen, helium, and CO_2. Curves for performance parameters as power output, thermal efficiency, economic performance, operating temperatures, consumption, solar share, etc. for several sample days of different seasons are shown and analyzed. Suggestions for optimized plant designs are made.

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