Applied Thermal Engineering 186 (2021) 116454

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Thermo-economic and sensitivity analysis of a central tower hybrid Brayton solar power plant

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ARTICLE INFO

Keywords:
Thermo-solar hybrid power plants
Overall plant model
Thermo-economic analysis
Sensitivity of levelized cost of electricity
Subsystems integration

ABSTRACT

A hybrid central tower thermo-solar plant working with a gas turbine is simulated by means of an in-house developed model and software. The model considers the integration of all plant subsystems. The calculation of the heliostat solar field efficiency includes the main losses factors as blocking, shadowing, attenuation, interception, and cosine effect. The simulation considers a Brayton cycle for the power unit with irreversibilities in the compressor and turbine, and pressure drops in the heat absorption and extraction processes. A combustion chamber burning natural gas ensures an approximately constant power output. The model is flexible and precise. At the same time it is fast enough to perform sensitivity studies on the efficiency of any subsystem and the overall plant. Thus, it allows for performing a thermo-economic analysis of the plant checking the influence of the main plant design parameters. The focal objective is to analyze the importance on the levelized cost of electricity (LCoE) of the key plant design parameters. The direct influence of parameters from the heliostat field and receiver (as tower height, distance to the first row of heliostats, heliostats size, receiver size and heat losses, etc.) on final LCoE is surveyed. Similarly, parameters from the turbine as pressure ratio, turbine inlet temperature, influence of recuperation and others, are also analyzed. The dimensions of the plant are taken from SOLUGAS prototype near Seville, Spain, although another location with quite different solar conditions in Spain is also considered. LCoE values predicted are about 158 USD/MWh. The analysis concludes that among several parameters surveyed, two of them are key in LCoE predicted values: turbine inlet temperature and solar receiver aperture size.

1. Introduction

Thermo-solar power plants constitute, among renewable energies, one of the best alternatives to lead the global energy transition from carbonized to decarbonized energy sources [1,2]. Solar central tower systems stand out because of their promising high efficiencies and concentration ratios. In these systems, a heliostat field reflects and concentrates the solar radiation onto a solar receiver, located at the top of a central tower. Nowadays, most commercial projects employ a Rankine cycle in order to transform the concentrated solar heat into electricity [3]. Nevertheless, Brayton cycles can make use of air or other gas instead of water to move a turbine. Therefore, they seem interesting in areas with good insolation ratios that almost always bring about scarce hydric resources [4]. These plants are flexible to operate because thermal energy storage [5,6] or hybridization can be implemented, reducing the undesirable impacts of solar energy fluctuations. A recent review on this point is due to Achkari and El Fadar [7].

In the research literature there are quite a lot works on central tower thermosolar plants but many of them are specialized in any of the subsystems. There are many accurate softwares to estimate and optimize solar field efficiencies either from theoretical assumptions or from MonteCarlo simulations as Campo Code [8], HFLCAL [9,10], SolTrace [11], and Tonatiuth [12]. A recent compilation and comparison among those models is due to Jafrancesco et al. [13]. Solar receivers technology, specially at the high temperatures required by Brayton cycles, is an open research field, both from the experimental viewpoint [14,15] or from computational fluid dynamics or materials perspectives [16]. There are also different tools to predict the performance of the power units producing the electricity from the thermosolar input as TRNSYS [17], Thermoflex [18], EBSILON Professional [19], EES [20], etc., that have been used by many authors.

Nevertheless, our approach is different: to build a precise but not too intricate model for the whole plant, controlling at any moment the

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https://doi.org/10.1016/j.applthermaleng.2020.116454
Received 29 April 2020; Received in revised form 4 November 2020; Accepted 8 December 2020
Available online 24 December 2020
1359-4311/