Abstract

Current anthropogenic intensification of climate change together with fossil fuel exhaustion have made imperative the necessity of a new energy generation paradigm looking for increasing generated power, but from cleaner sources that reduce associated pollutant emissions. Among the different renewable energy sources, Concentrated Solar Power (CSP) technology constitutes a very interesting option that employ solar radiation as main energy source. This technology stands out thanks to its ability to produce reliable, safe, efficient and clean power reducing, or even fully removing, pollutant greenhouse effect emissions associated with conventional fuel combustion. In Concentrated Solar Power systems, direct solar radiation is concentrated in order to obtain high temperature thermal energy that is transformed into electrical energy by means of a thermodynamic cycle and an electric generator. Main advantage of Concentrated Solar Power technology is its potential for hybridisation and its potential to store solar energy as heat, both in order to produce electric energy when desired and to complete and to rectify the inherently variable solar contribution.

This doctoral thesis is devoted to study, from the thermodynamic point of view, a Concentrated Solar Power plant, in particular a Solar Power Tower coupled to a hybrid Brayton cycle. In this way, the plant is considered to be set up by a heliostat field pointing to a solar receiver, where solar radiation is absorbed. Afterwards, solar heat is exchanged to a working fluid that develops a Brayton cycle. Above all else, the plant is aimed to work as baseload; in other words, to produce, and to deliver to the grid, a constant net power independent of solar radiation. As a consequence, the gas turbine is hybridised in series by means of a combustion chamber that ensures a constant turbine inlet temperature, and so, desired power output. When solar heat is not enough to reach imposed turbine inlet temperature, the combustion chamber burns natural gas completing and rectifying the solar heat.

There exists a significant lack of studies focusing on integrating all subsystems and analysing their inter-relationships and how they affect the global plant. In this way, the objectives of the thesis comprise the development of a theoretical model and its implementation in an own code for performing on-design and dynamic simulations that can offer valuable information of energy losses and configurations that lead to better output records.

According to the plant scale and to the heliostat field symmetry, two different sorts of systems are analysed in this doctoral thesis. First, a *SOLUGAS*-like plant with a power scale of about 5 MW and a polar field is evaluated. Alternatively, a larger power scale of around 20 MW and a surround field are examined too. In this case, *GEMASOLAR* plant is employed for parameters dimensioning. Nevertheless, a Brayton cycle is simulated instead of the Rankine power unit from *GEMASOLAR*. Following this trend, the comparison of two different power units (gas turbine and steam turbine) with similar power scales and solar subsystem size is one of the goals of this study.

Moreover, model predictions are validated by means of commercial software packages and by employing literature data. Apart from this validation, a comparison and a simple contextualization are also conducted for the different subsystem models output records.

Real meteorological data, such as solar direct normal irradiance and ambient temperature, are implemented in the code for the considered location. Additionally, other input parameters are taken into account in the solar subsystem like tower height, receiver size, heliostats reflectivity or mirrors area. Pressure ratio, turbine inlet temperature, working fluid mass flow, turbine and compressor efficiencies and heat release and heat absorption pressure decays are the main heat engine parameters for the plant modelling.

Some of the analysed output parameters are related to different kind of efficiencies: overall thermal efficiency, optical heliostat field efficiency, solar subsystem efficiency and heat engine efficiency. All cycle temperatures and heat rates are also computed. And other variables as fuel conversion rate, solar share, power output, specific fuel consumption and its associated greenhouse effect emissions are surveyed. From the thermo-economic

perspective, net energy, Levelised Cost of Electricity and its components are evaluated.

In order to analyse different working fluids performance, a closed cycle with heat exchangers is simulated. Thus, dry air, nitrogen, carbon dioxide and helium are tested. Additionally, the number of compression and expansion stages is also surveyed. Moreover, a pre-optimisation process is carried out looking for optimum pressure ratio configurations that lead to improved output variables.

Daily simulations show that the objective of producing a stable power output is accomplished. On the other hand, seasonal behaviour is translated into the width and into the height of output variables daily evolution curves, such as efficiencies and temperatures. A key outcome from off-design annual simulations is that heat engine improvements could lead to the largest enhancements of analysed overall plant output records.

Moreover, the recuperator influence is researched and concluded to be positive from both thermodynamic and thermo-economic viewpoints. Likewise, plant location is varied in order to evaluate its effect on plant records. Furthermore, sensitivity analyses allow to demonstrate that Levelised Cost of Electricity still presents potential for reduction regarding pressure ratio.

Besides those particular outcomes, this doctoral thesis reveals the importance of designing the Solar Power Tower hybrid gas turbine system as a whole, taking into account subsystems interactions. Therefore, this doctoral thesis can be useful in an initial step of the design of future Solar Power Tower systems developing hybrid Brayton cycles.