Hybrid thermosolar and micro gas turbine power plant for distributed generation: Thermoeconomic evaluation

I. Heras[1*], M.J. Santos[1], R.P. Merchán[1], J. García-Ferrero[1], A. Medina[1] and A. Calvo-Hernández[1]

[1*] Departament of Applied Physics, University of Salamanca, Plaza de la Merced s/n, 37008 Salamanca (Spain), +34 677565481, iheras@usal.es.

[1]University of Salamanca, Salamanca, Spain

1. Introduction

This work provides an integrated design of a small-scale hybrid solar power plant aimed at distributed generation of electrical energy. This technology may be especially interesting for remote areas with no access to electricity and advantageous solar conditions. The inherent limitations of a solar-only power plant (seasonal and meteorological sun fluctuations, nights) may be overcome with a hybrid operation mode. These systems can work uninterruptedly with an approximately constant power output, since the pressurized air of the cycle is heated from the concentrated solar irradiance and, when necessary, from the combustion of a fossil fuel. Then, the transformation of thermal energy to mechanical one is carried out by means of a Brayton thermodynamic cycle.

The main purpose in this work is to analyse the performance of the system for any real environmental and geographical conditions, through a thermodynamic model based on a reduced number of parameters, each one of clear physical significance. This is complemented with a thermoeconomic analysis, allowing an economical and environmental comparison among geographical locations and other power plants.

Conference Topics: Dish/Engine systems, Hybridization, Power Cycles

2. Thermodynamic design and validation

The hybrid thermosolar power plant is comprised of a parabolic dish that concentrates the solar irradiation in an integrated receiver used to heat pressurized air. In case of lack of solar irradiance, the working fluid is heated by a combustion chamber, whose fuel flow varies depending on the solar time, and seasonal and weather conditions. Then, the pressurized heated air performs the recuperative Brayton thermodynamic cycle as described in Fig. 1. The irreversibilities taking place in all subsystems (solar part, combustion chamber, micro-gas turbine, and the corresponding heat exchangers) have been considered in the model with home-software elaborated using Mathematica® and fully described by Merchán et *al.* [1].

An initial study was carried out for real values of direct normal irradiance, and ambient temperature, considering four representative days of the year and four different power outputs (30, 23, 15, and 7 kWe). This thermodynamic model is validated with the one developed by Semprini et *al.* [2] for only solar heat input. Subsequently, an analysis is made for two operating conditions: with and without solar contributions. Once the model is validated, a dynamic study of the power plant is carried out throughout one year.

Spain is a propitious country for solar renewable energy, because of its climatological conditions and by the available solar irradiance. Therefore, four different locations in Spain were chosen to compare the plant efficiencies, the fuel consumption and to perform an estimation of the greenhouse gases emissions, for both hybrid (solar and combustion chamber) and no solar operation modes.

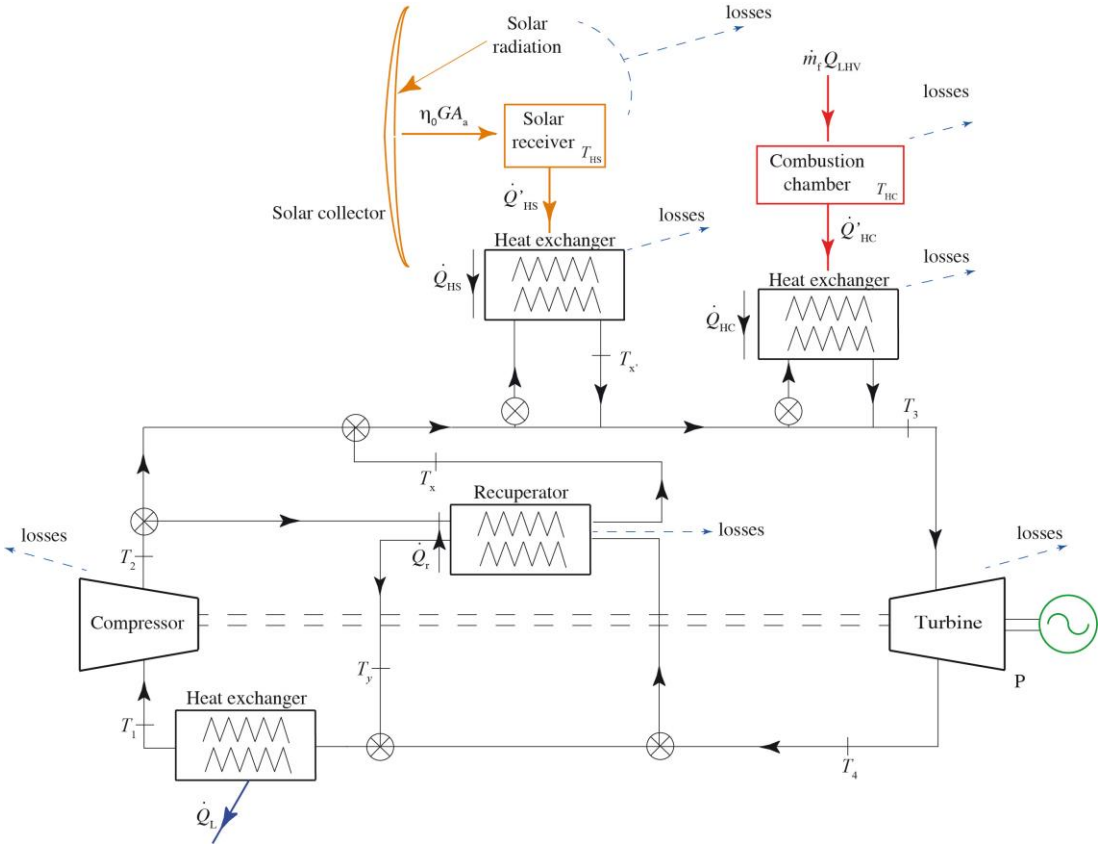

Fig. 1: Scheme of the hybrid solar micro gas-turbine plant considered.

3. Thermoeconomic evaluation

Thermoeconomic works are needed for further development of the parabolic dish power plants and its commercial implementation in order to properly accomplish their objective: the production of efficient and clean electric energy in a distributed way. Two thermoeconomic indicators were selected in this work: the levelized cost of electricity that represents the total cost of electricity generation over its lifetime and the CO_2 emissions as an import environmental performance indicator. This work delivers the values for both indicators, considering hybrid and combustion only operation mode, for the four different geographical locations selected in Spain. The costs estimations of the different components of the solar power plant, and manufacturing, transportation or installation costs are based on actual values.

4. Main results and conclusions

An off-design thermodynamic model has been developed, with analytical equations, for a power generation plant based on the hybridization of a parabolic dish solar collector and a Brayton micro gas turbine cycle. A dynamic study has been carried out, for four different locations in Spain. A thermoeconomic analysis compares the cost of electricity and the reduction of greenhouse gases emission of the different studied cases showing the potential of the hybrid parabolic dish power plant to become cost-competitive against non-renewable plants from the point of view of saving the consumption of fossil fuels and pollutant emissions in regions with high solar radiation and low availability of water.

References

[1] R.P. Merchán, M.J. Santos, A. Medina, A. Calvo Hernández, Renew. Ener., In Press (2017) DOI: 10.1016/j.renene.2017.05.081.

[2] S. Semprini, D. Sánchez, A. De Pascale, Solar Energy, 132 (2016) 279-293.