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Solar multiple optimization for a solar-only thermal power plant, using oil as heat transfer fluid in the parabolic trough collectors

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Abstract

Usual size of parabolic trough solar thermal plants being built at present is approximately 50 MW_e. Most of these plants do not have a thermal storage system for maintaining the power block performance at nominal conditions during long non-insolation periods. Because of that, a proper solar field size, with respect to the electric nominal power, is a fundamental choice. A too large field will be partially useless under high solar irradiance values whereas a small field will mainly make the power block to work at part-load conditions.

This paper presents an economic optimization of the solar multiple for a solar-only parabolic trough plant, using neither hybridization nor thermal storage. Five parabolic trough plants have been considered, with the same parameters in the power block but different solar field sizes. Thermal performance for each solar power plant has been featured, both at nominal and part-load conditions. This characterization has been applied to perform a simulation in order to calculate the annual electricity produced by each of these plants. Once annual electric energy generation is known, levelized cost of energy (LCOE) for each plant is calculated, yielding a minimum LCOE value for a certain solar multiple value within the range considered.
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Keywords: Solar-only thermal power plant; Parabolic trough collector; Solar multiple; Optimization

1. Introduction

Parabolic trough technology has proven to be the most mature and lowest cost solar thermal technology available today (Price et al., 2002). As a result, most of the projects for the construction of commercial solar thermal power plants are based on this type of collectors; several parabolic trough power plants are going to be constructed in USA, Spain, Northern Africa, Middle East, etc. Most of these plants consist of a solar field, a steam generator, a power cycle and a fossil-fuel fired back-up system.

Thermal storage system is not commonly employed in current parabolic trough plants, although there are some exceptions, like Andasol-1, in Spain, with 7.7 equivalent-hours of indirect storage in two tanks of molten salts (Relloso and Gutiérrez, 2008). In the latter case, storage is necessary to minimize the effect of transients, since only a 2% of fossil hybridization is allowed in Nevada, so this energy supplement is mostly used in order to prevent oil freezing. It is expected that more future parabolic trough plants will have thermal storage systems, because the operation strategy adopted in this way can be a scheduled mode, instead of the current solar dispatching mode.

Fossil-fuel hybridization is usually performed by means of an auxiliary oil heater able to maintain oil temperature above a lower limit, and a fossil-fuel fired boiler, which

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Nomenclature

e_{m0}	parameter defining the shape of the pump efficiency curve, –
k_p	constant for pressure drop calculations, –
$\dot{m}$	mass flow rate, kg/s
$\dot{m}_{ref}$	reference mass flow rate, kg/s
P_1	inlet pressure to the chosen section of the turbine, bar
P_2	exhaust pressure from the chosen section of the turbine, bar
$P_{1,ref}$	reference inlet pressure to the chosen section of the turbine, bar
$P_{2,ref}$	reference exhaust pressure from the chosen section of the turbine, bar
$\dot{Q}_{th,solar_field}$	thermal power produced in the solar field, W
$\dot{Q}_{th,PB}$	thermal power demanded by the power block, W
SM_{design_point}	solar multiple at design-point conditions, –
UA	overall heat transfer coefficient, W/°C
UA_{ref}	reference overall heat transfer coefficient, W/°C
ΔP	pressure drop, bar
$\eta_{generator}$	generator efficiency, –
$\eta_{s,pump}$	isentropic pump efficiency, –
$\eta_{s,\ pump_0}$	isentropic pump efficiency at nominal conditions, –
$\eta_{s,\ turbine}$	isentropic turbine efficiency, –
$\eta_{s,\ turbine_0}$	isentropic turbine efficiency at nominal conditions, –
θ	incident angle, degrees
$K(\theta)$	incident angle modifier, –

Acronyms

DCA	drain cooling approach
ET-150	Eurotrough-150
HTF	heat transfer fluid
LCOE	levelized cost of energy
TTD	terminal temperature difference

produces steam to turbine seals, in order to keep the turbine heated. Both systems operate during night and long non-insolation periods. Because of maximum fuel consumption is usually limited by the national electricity feed-in law, the remainder of annual fossil-fuel percentage for electricity production is very low if the solar plant is going to apply for incentives. For this reason no electricity production from fossil fuel has been considered in this paper.

The heat transfer fluid in the solar field is usually oil, so a steam generator is needed between the solar field and the Rankine steam turbine cycle. This particular configuration is called *heat transfer fluid* (HTF) technology.

The operation strategy adopted for the solar-only parabolic trough plant considered, is the solar dispatching mode, and the nominal electrical power has been set to 50 MW_e net, because it is an usual size for current parabolic trough plants. An optimization of the solar field size has been carried out for this particular configuration. As the solar field represents the major plant investment, calculation of the optimum field size is an analysis described in other works (Quaschning et al., 2002). The optimization presented in this paper involves the calculation of the solar multiple for which the levelized cost of energy is minimum. Solar multiple is defined as the ratio between the thermal power produced by the solar field at the design point and the thermal power required by the power block at nominal conditions:

$$SM_{design_point} = \left.\frac{\dot{Q}_{th,solar_field}}{\dot{Q}_{th,power_block}}\right|_{design_point} \quad (1)$$

This parameter represents the solar field size related to the power block, in terms of nominal thermal power. Design-point conditions adopted for this particular analysis will be summarized in Section 2.2.1. Solar multiple for solar-only plants is always greater that one, in order to achieve nominal conditions on the power block during a time interval longer than the one obtained if solar multiple is equal to one, as it can be seen in Fig. 1. Nevertheless, large solar multiple values for parabolic trough plants without thermal storage lead to a thermal energy overproduction that cannot be used for electricity generation. Although this configuration enables the power block to work at nominal conditions during longer periods of time, the cost of the kWh_e will be higher because there is a given non-profitable solar field inversion.

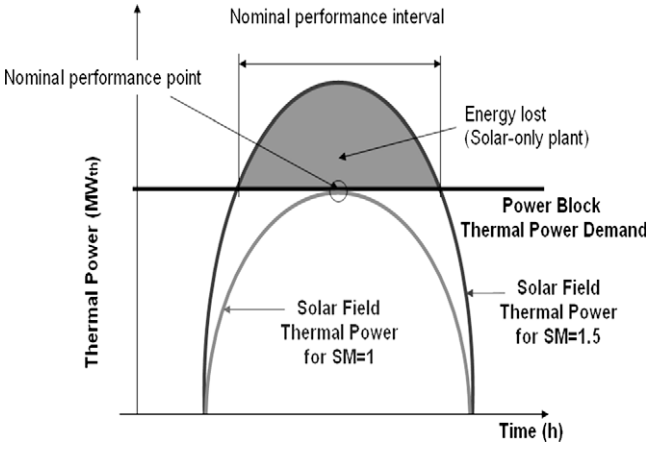

Fig. 1. Daily thermal power production for different solar field multiples.

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