



Technoeconomic assessment of an integrated solar combined cycle power plant in Greece using line-focus parabolic trough collectors



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ABSTRACT

Renewable energy sources and especially solar energy may be the answer to the increasing demand for energy, leading to the reduction of fossil fuel consumption and its associated negative environmental impact. An attractive solution to this problem could be the combination of renewable and conventional energy sources technologies such as the integrated solar combined cycle power plants (ISCCP). In this paper the operation of a 50 MW ISCCP with natural gas and parabolic trough solar collectors was simulated using TRNSYS software. The proposed power plant performance, fuel consumption and solar contribution were analyzed through six different simulation scenarios for different collector area. Two different modes of operation, namely power boost and fuel saving, were considered. Also, an economic analysis shows the optimal contribution rate of solar field taking into consideration the results of various simulation scenarios.

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1. Introduction

Integrated solar combined cycle power plants (ISCCP) are an innovative idea, in which solar heat is added to a conventional combined cycle power plant increasing the final electric output [1]. The solar field can be built near an already established conventional power plant (burning natural gas, coal or biomass) operating either in fuel saving or power boosting mode [2].

Various hybridization issues were theoretically approached, concerning efficiency, environmental and cost implications [1]. Different configurations of solar thermal and fossil-fired power plants and their effect on commercialization prospects were discussed among which ISCCP, where solar and gas steam temperatures do not need to match.

Several simulations of different solar field integration methods, such as producing saturated solar steam, generating superheated steam or periodically reheating flue gases, were reported [3]. Simulations aimed at finding the optimal solar contribution in a combined cycle plant, in order to obtain the highest solar thermal-to-electric conversion efficiency. In comparison with solar-only power plants, results showed that not only the efficiency of ISCCP was higher, but also the levelized energy cost, even with the incremental capital cost of a bigger Rankine cycle taken into account, was respectively lower.

A technoeconomic comparison of three different solar thermal technologies—integrated solar combined cycle system with direct steam generation, solar electric generating system, and integrated solar combined cycle system with HTF (heat transfer fluid)—was reported in Ref. [4], where the levelized energy cost (LEC) was the main criterion. An integrated solar combined cycle with higher solar contribution than commonly used was modeled in Ref. [5], where the proposed model uses hot flue gases of a gas turbine for heating the HTF of the solar thermal field and for preheating the feedwater. Different integration methods of solar energy in a coal-fired plant such as preheating, evaporating or both arrangements were discussed in Ref. [6].

Archimede Project is the world's first integration of a thermodynamic solar energy system into gas-fired combined cycle power plant in Sicily–Italy [7]. It consists of two 380 MWe gas-fired combined cycle power plants and a 5 MWe parabolic trough solar field with a collector surface of 30,000 m². This solar field makes use of molten salts as heat transfer fluid (HTF), instead of conventional synthetic oils, allowing higher operating temperatures. Solar steam can then be used to supplement gas steam even at high pressure and temperature levels.

The SEGS VI in California with a collector surface of 188,000 m² and net turbine capacity of 30 MW was modeled in TRNSYS based on STEC library components. Good agreement between model predictions and plant measurements was reported and errors usually less than 10% were found [8].

Greece, with its pivotal position in southeast Europe, is emerging as a strategic energy hub in the region. Historically

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heavily reliant on lignite for its electricity, natural gas is transforming Greece's power sector. The ISCCP will allow for a flexible transition from the present combined cycle power plants based on fossil fuels to future plants based extensively on solar energy.

The aim of this paper is the development of a flexible and easy to apply TRNSYS model of ISCCPs based on natural gas-fired power plant and parabolic solar collector field. Secondly this paper aims at investigating various contribution rates of solar field to exported electricity and how this criterion affects the viability of the investment.

2. Integrated solar combined cycle power plants

Integrated solar combined cycle power plants not only produce energy via a gas turbine in a Brayton cycle, but also take advantage of the hot flue gases which are directed to a steam Rankine cycle (Fig. 1). Brayton cycle consists of a compressor, a combustion chamber and gas turbine. Air is compressed by the compressor and then sent to the combustion chamber, where it is mixed with fuel. After ignition, hot flue gases are then passed on to the turbine forcing its blades to turn. The turbine shaft is fixed on an electric generator's shaft, thus producing energy. In combined cycle systems, Rankine cycle takes advantage of the remaining heat of flue gases, instead of simply discharging them to the atmosphere. Its basic parts are the steam generator, one or more turbine stages and the condenser. Steam generator is a set of heat exchangers in series, with a hot gas or fluid flowing in the hot side and water or steam in the cold side. The produced steam flows to the turbine stages of multiple pressure levels starting from high pressure, where it expands and gradually transfers its energy to the turbines shaft. Total shaft work is the mechanical input of an electric generator. The steam is then condensed to form feedwater in the condenser. Feedwater can be deaerated and preheated before it is fed back to the steam generator. Integrating solar field is usually done in medium or low pressure stages, where a second steam generator is added in parallel between medium or low pressure and the feedwater flow. In the next section such a power plant operating in

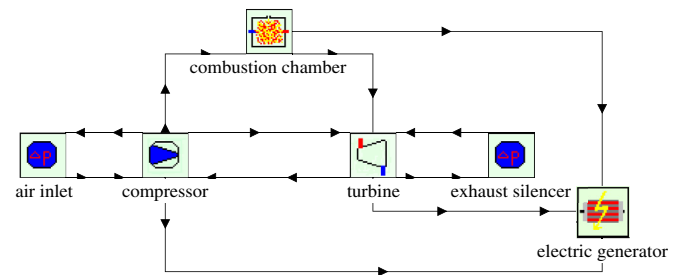


Fig. 2. Brayton cycle model.

power boosting mode and fuel saving mode will be presented and simulated using TRNSYS 16 and STEC Library 3.0 [9].

3. ISCCP TRNSYS model

The design of an integrated solar combined cycle power plant is rather complex since it involves the combination of three main systems: the Brayton cycle, the solar field and the Rankine cycle. In the following paragraphs each system is presented separately for better understanding.

3.1. Brayton cycle

In Fig. 2 the Brayton cycle model is presented, where the main parts are the compressor (type 424), the combustion chamber (type 426), the turbine (type 427) and the electric generator (type 428). Temperature ($^{\circ}\text{C}$), pressure (bar) and mass flow (kg/h) of the working air are the inputs of the compressor, where the air is compressed by a ratio of 10 in order to achieve the appropriate pressure, temperature and enthalpy for the combustion chamber. Also, a small fraction of air is subtracted from the compressor for turbine cooling. The combustion chamber's parameters concern the chemical composition and the lower calorific value (kJ/h) of the fuel—in this case natural gas—and together with its inputs this

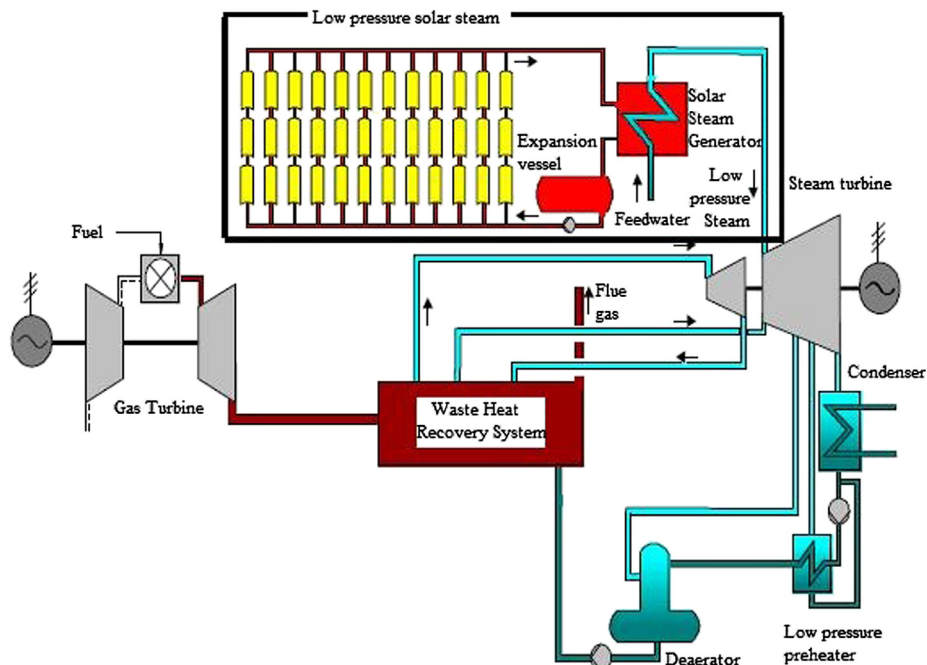


Fig. 1. Integrated solar combined cycle power plant [10].

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