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ELSEVIER
Solar Energy 80 (2006) 1270–1276
SOLAR ENERGY
www.elsevier.com/locate/solener

INDITEP: The first pre-commercial DSG solar power plant

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Received 14 October 2004; received in revised form 10 February 2005; accepted 8 April 2005
Available online 22 July 2005

Abstract

This paper presents the conceptual design of the first solar power plant using Direct Steam Generation (DSG) in a parabolic-trough solar field. Experience and know-how in the DSG process acquired during the DISS project were applied in designing the solar field of this plant. The 5-MWe plant is composed of a DSG parabolic-trough solar field connected to a superheated steam Rankine power cycle. The solar field produces 410 °C/70-bar superheated steam. Detail engineering of this plant is currently underway within the framework of the INDITEP project, which is promoted by a German-Spanish consortium with the financial support of the European Commission (Contract No. ENK5-CT-2001-00540). The main design objective is to assure high operational flexibility and reliability. This is the reason why a robust superheated steam turbine has been selected, though the efficiency of its power block is modest.

Keywords: Solar energy; Solar thermal power plants; Direct steam generation; Parabolic-trough collectors

1. Introduction

Direct steam generation in the absorber pipes of parabolic-trough solar collectors (the so-called DSG process) is a promising option for reducing the cost of solar power plants using this type of collector. The feasibility of the DSG process in horizontal parabolic-trough collectors had already been proven in the DISS project (Eck et al., 2003) and the valuable experience and know-how acquired there is now being applied in the INDITEP project in the design of the first pre-commercial DSG solar power plant, where the thermal energy delivered by a DSG solar field is used to feed a superheated steam Rankine cycle.

The INDITEP project is the logical continuation of the DISS project, because the design and simulation tools developed in it for DSG solar fields are now being used in INDITEP, and most of the partners were also involved in the previous project. INDITEP is promoted by a Spanish-German Consortium of engineering companies, power equipment manufacturers, research centers and businesses involved in the energy market: Iberdrola Ingeniería Consultoría (Project Coordinator), CIEMAT, DLR, FLAGSOL GmbH, FRAMATONE, GAMESA Energía Servicios S.A., INITEC Tecnología S.A., Instalaciones Inabensa S.A. and ZSW. The European Commission also provides financial support to the project under Contract ENK5-CT-2001-00540.

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0038-092X/$ - see front matter
doi:10.1016/j.solener.2005.04.019

Nomenclature

DISS	direct solar stem	p	pressure, bar
DSG	direct steam generation	T	temperature, °C
PSA	Plataforma Solar de Almería	q_m	mass flow, kg/s

2. Basic requirements and design parameters

Three basic requirements were defined for the design of this first pre-commercial DSG solar power plant:

1. Since there is no previous experience on the operation of a commercial DSG power plant under real solar conditions and its performance under solar transients can only be predicted by means of simulation tools, the power block selected must be robust, and operable under flexible conditions in order to assure durability and reliability. Higher priority has therefore been given to power block robustness and flexibility, while efficiency was considered less critical for this first DSG plant.
2. The plant must be small in order to limit the financial risk for investors. Operating stability of a multi-row DSG solar field under uneven distribution of solar radiation and solar radiation transients must be proven in this first plant. Though both experimental and simulation results obtained in the DISS project showed that multi-row DSG solar fields can be controlled under solar radiation transients, this has to be experimentally proven in this first plant before implementing large DSG commercial plants.
3. The solar field must be designed to operate in recirculation mode because the analysis of the three basic DSG operation modes (i.e., injection, once-through and recirculation) performed in the DISS project demonstrated that the recirculation mode is the best option for commercial DSG solar fields (Eck and Zarza, 2002).

A superheated steam turbine was chosen in fulfillment of the first requirement. Though there are also saturated steam turbines available on the market, their operation is less flexible, because they are not designed for the daily start-up and shut-down that are usual in solar power plants. This kind of operation would reduce the life time of saturated steam turbines considerably and would require frequent revisions and costly maintenance. Saturated steam turbine manufacturers usually recommend continuous operation, with low-load overnight conditions.

A net nominal power of about 5 MWe was defined for the power block for this first plant as a good compromise between a larger, more profitable size and the small size required to limit the financial risk for investors.

Superheated steam pressure was not to be much higher than 60 bar, because the DISS project test results at 30 bar and 60 bar were very good (Zarza et al., 2002), while solar field operation at 100 bar showed that intermittent operation at this pressure could cause small leaks in flanges and non-welded connections from repeated thermal expansion and contraction of the piping, though the importance of this possibility could be reduced by replacing flanges by welding, a steam pressure of about 60 bar was defined for the plant to assure availability and reliability.

3. Power block

Several ALSTOM, SKODA and KKK superheated steam turbines were compared, taking all the basic design requirements into consideration. Fig. 1 shows a simplified scheme of the power block finally selected for the plant, with the main technical parameters for flow rates, pressures and temperatures. The technical parameters not displayed in Fig. 1 are listed in Table 1.

Though the small size of the power block selected could, in principle, be a handicap for its commercial profitability, both its implementation and exploitation could become financially feasible if the external financial incentives usually given to demonstration plants were obtained. Even though it is not very efficient, the power block selected has a simple Rankine water/steam cycle and its operation is very robust and flexible, which were considered very important features.

3.1. Steam turbine

The steam turbine included in the power block is a reliable, robust KKK non-reheat superheated steam turbine offered by PASCH (model CFR5G6a + AFA66G-T5a). The outlet of the turbine high-pressure stage is connected to the inlet of the low-pressure stage. The isentropic efficiency of the turbine is 72% at the nominal steam flow rate of 26 ton/h and decreases to 28% at 6 ton/h. One of the main advantages of this KKK turbo-generator is that with adequate inlet pipe purging, it can be started up directly without preheating, and is