Solar cogeneration with parabolic trough collectors in TRESERT

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1. Introduction

At the SERT (School of Renewable Energy Technology) in Phitsanulok, Thailand a solar thermal electric system has been erected within the project TRESERT (Trigeneration from Renewable Energy at SERT) by the Solarlite GmbH. Scientific assistance has been provided by the SERT and the German Aerospace Center (DLR). The project aimed at demonstrating simultaneously solar electricity production, heating and cooling at small scale with a single solar system.

2. Layout of the installation

The main components of the installation are solar field, steam turbine and chiller.

The solar field (Fig. 1) consists of parabolic trough collectors of the type SL4600 with a total surface of 662m² erected in two rows in north-south axis, which are connected in series. In the collectors focal line a vacuum receiver as used in power plants with a diameter of 70mm has been placed, suitable for direct steam generation.

Fig. 1. Solar field with SL4600 collectors

As heat transfer medium water is being used. The system has been set-up for direct steam generation running in the recirculation mode. In the solar field water gets pre-heated and then evaporated, leaving with a pressure of 22 bar_{abs} and a temperature of 217°C according to the nominal live steam parameters of the turbine. No superheating is applied; the turbine can be operated with saturated steam. Entering a steam drum of 0,75 m³, water and steam are separated, with the water being recirculated. After running through a steam dryer, the saturated steam enters the turbine. The steam leaves the turbine at 1.3 bars and gets condensed in two serial heat exchangers. The condensate then flows to the feed water tank with deariation and is pumped back to the solar field by the feed water pump. Fig. 2 displays a simplified layout of the plant and Fig. 3 shows a general view of the power block.

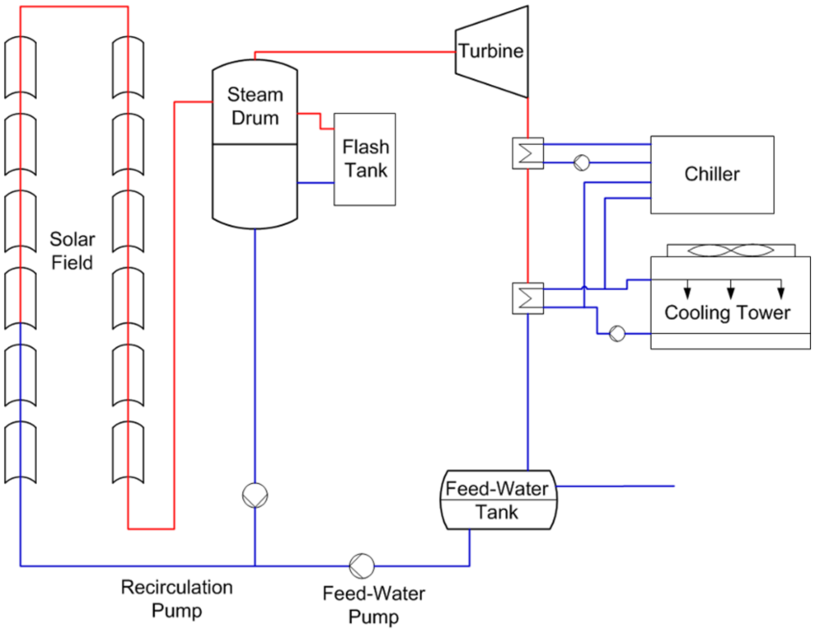

Fig. 2. Simplified layout of the plant

Fig. 3. General view of the power block. Left: Cooling tower. Middle: Turbine and condensators. Right: Steam drum and feed water tank

The turbine has a nominal electrical output of approximately 22 kW at an inlet pressure of 22bar (Table 1). Its efficiency and part load characteristics are unknown.

Fig. 4. Turbine with generator and condensator

Turbine Skinner SB 18	
Nominal gross electrical power	22 kW
Nominal pressure inlet	22 bar
Steam outlet pressure (before condensator)	1.3 bar
Efficiency, part load characteristics	Unknown
Minimum pressure for operation according to manufacturer	10 bar

Table 1: Turbine characteristics

The steam from the turbine enters into a condensator (upper white pipe in Fig. 4), which supplies heat to an absorption chiller. This fits well to the working temperature of 88 – 92°C of the Century AR-D 30 L2 machine. Running with a single stage it delivers a nominal cooling power of 100 kW at a COP of 0.7.

Additionally or alternatively the turbine's waste heat can be used to produce hot water (lower white pipe in Fig. 4). No consumer has been connected yet though. As for now the heat is dissipated by a cooling tower.

Fig. 5. Absorption chiller

3. First experiences with the plant

A major obstacle at the beginning of the project was to find a small scale steam turbine. After a worldwide screening only the Skinner turbine was found to be feasible, as it has already been technically proven and financially acceptable.

During the planning process it was found, that the plant had to be carried out similar to a great sized power plant. Safety issues and control of the hydraulic circuit are quite similar, even if not necessary in such an extent. About 100 instruments as temperature, pressure, level and flow meters and numerous valves were installed. Accordingly already planning the installation has been laborious.

Unlike in a greater power plant several functions were not automated. A control system has been implemented, which includes automatic as well as manual operations. Thus the plant needs two persons for operation.

The plant has been commissioned between November 2011 and February 2012. After this period the plant has been operated for several days, producing electricity and cooling.

Starting up the solar field is comparatively simple. After running the recirculation pump the solar field can be tracked. The saturated steam generation in the recirculation mode is a comparatively stable process. Typical safety features as e.g. automatic defocusing of the collectors when the temperatures go beyond the limits are indispensable and facilitate operating the solar field.

Operating the turbine is more demanding for the operation team. Valves need to be opened carefully first for pre-heating, later the turbine receives more steam for full operation without surpassing admitted gradients. Also synchronising the generator to the grid and connecting to the grid happens manually. A monitoring system assists the operators.

Solar field, turbine and chiller have been running jointly. In part load the turbine runs with sliding pressure. The live steam pressure develops according to the solar power and the consumption of the turbine. If the solar power gets less than the nominal power input of the turbine, the pressure drops. Whilst according to the manufacturer the minimum pressure for operation is 10 bar, it was found during operation, that the turbine would still run at 5 bar with an electrical output of 2 kW.

The steam drum not only works as a separator, but also as short term storage according to the Ruth's principle. In first experiments it could bridge about 10 minutes of low radiation.

Up to now data were only partly logged. The data measurements allow operation but not yet evaluation, as some key parameters are not yet being logged.

The amount of electrical consumption of ancillary components is relatively high. In part load therefore situations with no net electrical output can occur.

The operating team nowadays includes trained personnel of the SERT and students of the SERT. As the installation contains all major components of a solar thermal power plant, it is quite suitable for introducing them into the solar thermal power technology. In future it may be used to train operators of thermal solar power plants as part of a training course within the SERT.

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Summary

A small solar cogeneration system has been set up and operation has started. Solar field, turbine and chiller have jointly been running, producing electricity and chilled water. This has been achieved under a semi-automatic operation mode. Solar field and power block are simple to handle though with some experience.

As far as the authors know, it is for the first time, that a CSP (Concentrating Solar Power) plant has produced electricity and cooling energy simultaneously. Additionally it is the first CSP plant in a power range below 100 kW electric.

Accordingly there are several lessons learnt. A major obstacle for small scale solar thermal power production is the availability of matching and cost efficient steam turbines or other rankine expansion machines. Only a few low power turbines are available, and few parameters are known about them. Their low efficiency faces a relatively high electrical consumption of the ancillary equipment necessary to run the power plant. As a result it is highly recommendable to include in any pre-design calculations of the annual plant output, regarding also part load cases.

Significantly more effort has been necessary for engineering, instrumentation and control than expected. To reduce costs of small scale CSP installations a package solution including turbine, generator, heat exchanger(s), condensator and plant control will be essential.

As the plant has all the main features of a solar thermal power plant, students can be educated well to understand principles of solar thermal systems and cycles with steam turbines by operating the plant. Even future operators of CSP plants can be schooled at the site in combination with theoretical courses at the SERT.

The plant will in future be operated by the SERT team.