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Transient analysis of integrated Shiraz hybrid solar thermal power plant

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ABSTRACT

Shiraz solar thermal power plant is designed for 250 kW power supply during available sun radiation. It is decided to promote the field of collectors by installing a large parabolic collector and combining the system with a 500 kW hybrid boiler. For the new integrated configuration, thermodynamic analysis is required for engineering design and evaluating thermal performance.

For the new system, transient simulation is performed under different working conditions. In the plant, each component is simulated transiently, by considering initial condition and capacity rate of the component as well as all the connecting pipes and instruments. Results of the simulation for thermal performance are compared with field experimental measurements for several periods. Taking into account the thermodynamic concepts and the results of numerical and experimental analysis, the best operation strategies are selected for optimum performance and control philosophy based on the new integrated collector.

1. Introduction

The increasing rate of energy demand all around the world and the crises of environmental pollution is one of the major challenges that man has to deal with to develop new energy source for a sustainable development. Green house effects and global warming have made it crucial to devise new green technologies and expand the current rate of renewable energy generation.

Being available in vast areas around the world, solar energy is one of the most important renewable energy sources to comply with of the world's need to energy. Due to high prices and low efficiencies encountered for developing solar thermal power plants, selecting efficient working philosophies and improving the working condition of current power plants are very important. Another problem faced for using solar thermal power plants is the unreliability encountered due to variation in environmental conditions such as cloud and wind effects which result in oscillation in the plant performance. In order to resolve the reliability problem, different methods are proposed such as combining the solar thermal power plant with another plant or adding an auxiliary boiler.

Shiraz solar thermal power plant with the initial design for 250 kW has been installed in the city of Shiraz. This plant consists of two cycles: an oil cycle and a Rankin steam cycle. In order to make this plant more reliable and to increase its capacity, a new collector is designed, accompanied by an auxiliary boiler, these elements are integrated into the initial power plant. For a detailed study of the overall system and evaluating the working philosophy, a fully transient simulation of the system is needed. As a result of calculations, a report of the transient performance of different components can be obtained to optimize the set points defined in the system control philosophy. Thermal simulation models are strong tools which have been developed recently for several thermal systems. Stuetzle et al. (2004) with a semi transient modelling investigated the set points for 30 MW SEGS VI [1]. Garcia-Barberena et al. (2009) evaluated the effect of operational strategies on the performance of a solar thermal power plant using SimulCET [2]. Yao et al. (2009) performed a transient simulation on the pioneer 1 MW solar thermal central receiver system in China and studied the system performance under different working conditions [3]. These codes are made for special purposes and they are not available for the present specific simulation.

Therefore in this study a new code is developed in TRNEdit environment of TRNSYS which is specially designed for the Shiraz solar thermal power plant (SSTPP). The developed code is unique in the sense that it has various capabilities to comply with elements

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Nomenclature

A	area m^2
F_R	collector heat removal factor
h	enthalpy
I_t	incident solar radiation $kJ/s.m^2$
m	mass flow rate kg/s
Q_u	useful energy gain kJ/s
T	temperature
U_L	collector overall loss factor W/m^2 K

Greek symbols

ΔT	temperature difference °K
$(\tau\alpha)_n$	normal transmittance absorptance
η	efficiency

Subscripts

i	entering
e	exiting
env	environment
es	isentropic
s	steam

used in SSTPP and has the best approach toward finding highest performance of SSTPP.

2. Methodology

The 250 kW design of Shiraz solar thermal power plant consist of an oil cycle and a steam cycle (Cycles B and C in Fig. 1).

In the new designed system, a 100 m collector is integrated into the system (inserting cycle A of the Fig. 1, to the previous system). Considering the environmental conditions such as wind speed design condition, a computer code is developed for an evacuated tube of parabolic trough concentrating collector based on Eq. (1) [4].

$$\dot{Q}_u = A_c\left[F_R(\tau\alpha)_n I_t - F_R U_L \Delta T\right] \tag{1}$$

The performance of the collector field is highly dependent on the environmental condition such as dust and wind and typical conditions presented in Fig. 2. These parameters are inserted through fouling factors in the collector performance relations. In the new 500 kW design, an auxiliary boiler is also integrated into the system. The collectors' field is designed to generate 300 kW power and the remaining power to reach the 500 kW nominal capacity would be provided by auxiliary boiler integrated into the system. The boiler is also to keep the output power steady and reliable when the absorbed irradiance is low due to technical or environmental deficiencies.

In this paper one of the control philosophies proposed for the system is considered. With parametric study, control set points are evaluated for the optimum performance of the system. In order to study the system performance, a computer code is prepared and a transient simulation is performed on the entire system. In the first stage of simulation, the code is used to study the performance of the old system to compare the results with the collected data from the power plant. For the transient modelling, attempt is made to take into account the parameters such as wind effect and heat capacities of all components. The thermal programming is modelled in the computer code similar to the approach developed by Schwarzbözl [5]. With a lumped capacity method using an energy balance for a mass with capacity C and initial temperature T_0, which is heated by a capacity flow rate $\dot{C}$, the capacity of the system is inserted into the prepared transient computer code. For the insulated connecting pipes, their heat capacities are also considered and the pipes are modelled using plug flow model [5]. The pipes are divided into many segments and the environmental loss is evaluated by summing the losses from every single segment by Eq. (2).

$$\dot{Q} = \sum_{i=1}^{n} (UA)_i (T_i - T_{env}) \tag{2}$$

Pumps in this simulation are single speed with fixed flow rates. Effects of pumps heat generation on the system fluid temperature increase are neglected.

Working fluid characteristics are temperature dependent which is considered through the entire simulation. For example the VP1 thermal oil is used in the new collector loop. Typical variation of its

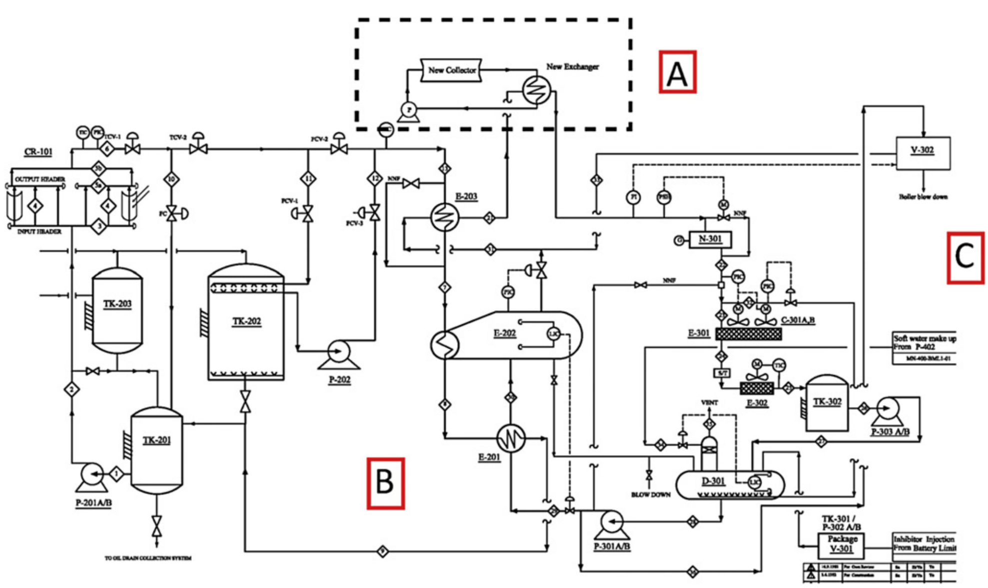

Fig. 1. Process flow diagram of the new designed system.