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Technical note

Automatic control strategies for hybrid solar-fossil fuel power plants

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ABSTRACT

Solar electrical generating systems are a class of solar energy systems which use parabolic trough collectors (PTC) to produce electricity from sunlight. In order to provide power production, one of the major challenges is to held the collector outlet temperature or steam temperature around of a specified set point by adjusting the flow rate of the heat transfer fluid (HTF) within upper and lower bounds. In some cases, an auxiliary heater can be used to provide heat in absence of solar radiation or during cloudy days. This paper presents a comprehensive study of three control schemes proposed to keep the steam temperature around its set point by adjusting the fuel (propane) and air mass flow rate of the auxiliary fossil fuel-fired heater. A non-linear dynamic model was developed in SIMULINK® to study the performance of each control scheme. Variation of controlled and manipulated variables along with the valve signals is presented for a period of a cloudy day. The results showed that the combination of feedforward and three level cascade control is the best alternative to track the temperature set point. It was also found that a single three level cascade control without feedforward had less oscillations and low fuel consumption compared to the others control strategies.

1. Introduction

Solar electric generating systems (SEGS) use parabolic trough collectors technology (PTC) to produce electricity from sunlight. Parabolic trough collectors are long rows of mirrors with a parabolic shape that concentrates solar energy on an absorber pipe, typically stainless steel tube with a selective absorber surface, that passes trough the focus of the parabola. These collectors have a system that allows them to track the sun by rotating around a north–south axis. A thermal oil is used as a heat transfer fluid (HTF), which circulates trough the absorber pipes and is used to transfer the energy gained from the solar radiation to the thermal power cycle. The HTF leaves the PTCs at a specified outlet temperature and after that is pumped to several heat exchangers (See Fig. 1) where the heat gained is transferred to the working fluid, water or steam, which is used to drive a steam turbine coupled with a generator to produce electricity [1].

In order to provide stable power production one of the major challenges is to keep the collector outlet temperature or steam temperature near to a specified set point, by adjusting the flow rate of the HTF. The HTF temperature at collector outlet is affected by variations in the sun intensity, the HTF temperature at collector inlet and its volumetric flow rate. The ambient conditions, specially variations in ambient temperature and wind speed also influence the outlet temperature but their influence is small [1].

During recent years, many control methods have been employed in Concentrated Solar Power applications to overcome the problems caused by the intermittent nature of solar radiation [2]. The use of PID controllers has been studied but the results have showed that the traditional Ziegler–Nichols tuning method for PID produces an unstable closed-loop system [3] and PID controllers with fixed tuning parameters have been usually restricted as backup controllers [2]. On the other hand, feedforward controllers are used in industrial applications to correct the effect caused by external and measurable disturbances, in fact new generation solar plants with direct steam generation are implementing PID controllers combined with feedforward controllers [4,5]. Cascade control, another traditional control technique, is used in solar power plants because it splits the control problem in two scales and two or more control loops, employing a master control loop which controls the process output and slaves control loops that measure intermediate variables and cancel the effects of the disturbances before the controlled variable is affected [2,6].

Advanced control schemes have also been implemented [7]. Johansen et al. [8] implemented a gain-scheduled pole placement

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Nomenclature

$\dot{Q}$	heat transferred [kW]
V	volumetric flow rate [m^3/s]
$A_{abs, surf}$	surface area per unit length [m]
C_p	specific heat capacity at constant pressure [kJ/kg − K]
D	diameter [m]
L_{col}	length [m]
n	number of collectors
T	temperature [K]
V	volume [m^3]
ρ	HTF density [kg/m^3]
abs	absorbed, absorber
amb	ambient
col	collector
Exp	expansion vessel
furn	furnace
HTF	heat transfer fluid
in	collector inlet
Loop	collector loop
out	collector outlet
surf	surface

control strategy on a pilot-scale solar power plant, the results showed that the gain-scheduled control strategy performs very well because it can effectively handle the nonlinearities of the plant. Farkas and Vajk [9] presented an internal model-based controller (IMC) designed for the operation of a solar power plant and found that IMC met the quality requirement of the plant control under clear radiation. Fuzzy logic CONTROL (FLC) was first applied by Rubio et al. [10], who performed the application of Fuzzy logic control on a distributed collector field (DSC); the control system showed high degree of robustness and performance despite of the variation of its operating conditions. FLC shows a high performance when there is a certain level of uncertainty or when the knowledge of the process operation can be translated into a control strategy that improves the results achieved by other classical strategies [7].

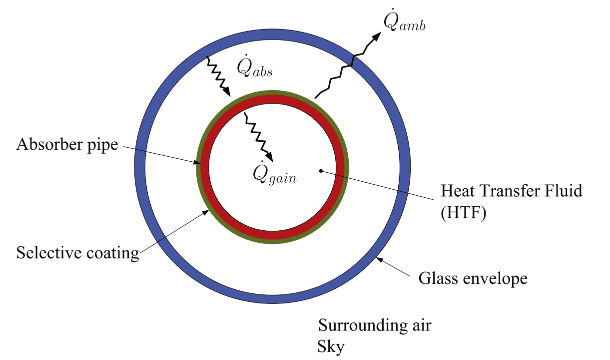

Fig. 2. Heat transfer in HCE for the simplified model. Adapted from Ref. [12].

As it was mentioned, all previously described techniques were focused on controlling the solar collector outlet temperature by varying the heat transfer fluid (HTF) flow rate (the manipulated variable) through the collector field [11] but no auxiliary backup was considered. On the other hand, modeling the solar collector field with an auxiliary fossil fuel-fired heater creates an additional manipulated variable that could increase the performance of traditional control schemes. This paper presents a comprehensive study of the performance of three different control schemes to control the steam temperature that leaves the boiler heat exchanger by adjusting the fuel and air mass flow rate of the auxiliary fossil fuel-fired heater instead of the HTF flow rate, which was considered as a disturbance variable. These control techniques were evaluated in order to determine the system robustness and the best scheme to track the temperature set point when fossil fuel-fired auxiliary heater is used in PTCs solar plants.

2. Solar plant description

Solar thermal power plants are systems for power and electricity generation by employing solar radiation as a thermal source.

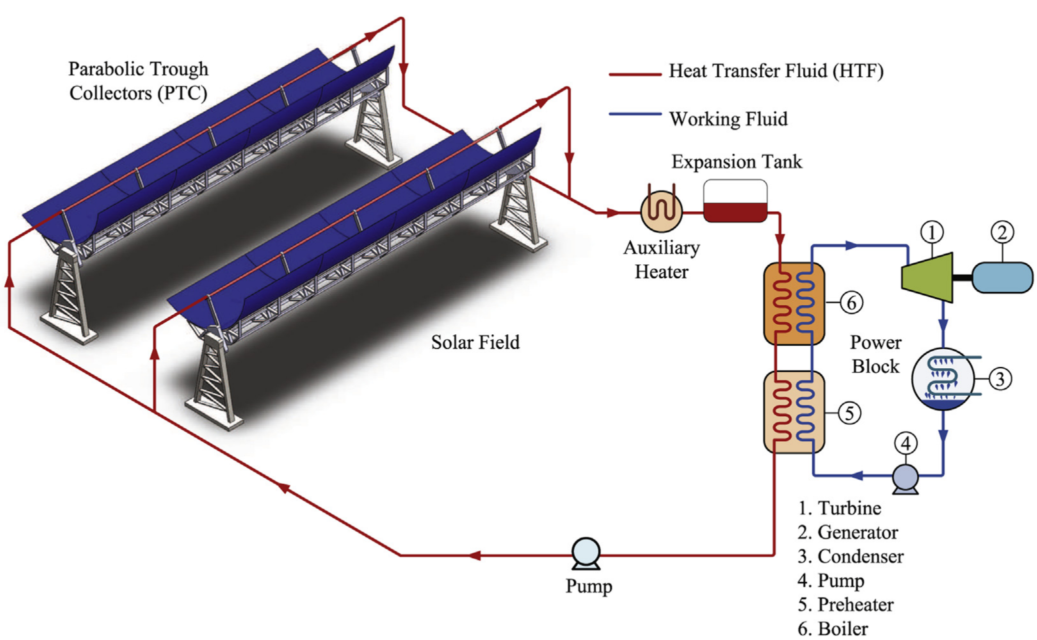

Fig. 1. Schematic diagram of the SEGS VI Solar Thermal Power Plant with fossil-fired backup. Adapted from Ref. [12].