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Control design model for a solar tower plant.

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Abstract

This paper deals with the development of a control design model for a 1MW Solar Tower equipped with a heat storage facility. This model is precise enough to achieve a good prediction of the responses but is also simple enough to avoid computational burden. The paper presents the assumptions and equations used for the different components of the plant. The behavior of the model developed in Matlab/Simulink[tm] is qualitatively validated by closed loop simulations. The control used for these simulations is also given. It consists of two levels, the upper level being an automaton whose outputs are the set points of the lower level controllers.

Keywords: Solar Tower; Superheated Steam; Storage; Control;

1. Introduction

The development of an advanced control strategy is an efficient means to improve the maneuverability of the superheated steam Concentrated Solar Power plant e.g. the performance, the reliability, the plant life consumption and the safety. The main objective for the control is to track the power demand and to limit the thermal load experienced by the main components. The design and tuning of such a control system is however particularly difficult due to the complexity of the phenomena involved in this kind of plant. Among the major concerns are the non linearity and the coupling between the variables which make the system highly complex. To deal with such a process a model is thus mandatory to test and tune the control design before an on-site implementation.

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The references [2, 3] give a detailed model for the heliostat field and the boiler for the CSP Plant considered in the following. This model is very useful for the design of the plant and for performing some detailed analyses. Different from this, a simpler model is suggested in the present paper, which is specifically used to design the control system. For this purpose, intensive simulations are necessary, on the one hand to manipulate and parameterize an appropriate control structure and on the other hand to check if the process can be safely maintained by the control at the desired operation conditions under different scenarios. For instance, if a process variable (pressure, level, temperature) oscillates during a simulation, one can try to decrease the corresponding controller gains. The response obtained in simulation with the new gain may however be too sluggish and another control structure can be considered. This trial and error approach to design the control loops can be time consuming and a fast model is needed to be able to make a lot of runs. The model simplifications lead to a shorter simulation time and lessen the numerical difficulties so that intensive simulations can be done to adjust the control design. Moreover, the simple model can also be used in advanced control solutions such as a Model Predictive Control [1] for example which generally requires a lot of simulation to compute the control sequences.

Nomenclature

Cv	Valve characteristic coefficient		Subscripts	
DNI	Direct Normal Irradiation (W/m^2)		EV	Evaporator
E	Exchange efficiency		SH	Superheater
L	Level (mm)		c	Cold or convection
M	Inertia parameter (kg)		cd	Condensation
N	Number		d	Desuperheater
O	Opening		dc	Downcomer
Q	Heat Flux (W)		ev	Evaporation
S	Heat surface (m^2)		f	Feedwater
T	Temperature (K)		h	Hot or heliostat
V	Volume (m^3)		l	Latent
W	Electric Power (W)		$loss$	Loss
c	Heat capacity(J/K)		m	Massic or metal
k	Proportional gain		oil	Oil
h	Specific enthalpy (J/kg/°C)		r	Riser
h	Heat coefficient (W/°C/m^2)		s	Steam
m	Mass (kg)		sat	Saturation
p	Pressure (Pa)		sd	steam under water level in the drum
q	Flow rate (kg/s)		t	Turbine or total
α	Steam fraction		v	Volumic
λ	Fluid thermal conductivity (W/m/°C)		w	Water
ρ	Density (kg/m^3)			
η	Efficiency		Upperscripts	
			in	Inlet
			out	Outlet

In the 1st section the paper presents the process with a field of heliostat, a solar tower with a steam boiler, a steam and water storage system, oil circuits used to store the heat and a steam turbine. The 2nd section presents the simplified equations used to describe the different components. The model of the boiler is based on the drum boiler model developed by Aström & Bell [4]. The steam accumulator model is described by a two phase system representing the condensation and the evaporation of steam and water and is based on the work of Stevanovic & al. [5]. The turbine is represented by a model that is classically used for control. Simple models for the superheater and desuperheater are also given. The implementation of the model in Matlab Simulink^{tm} as well as the main control loops (level, pressure and temperature) are presented in the 3rd section. A two-level control structure is proposed to manage the storage system. The upper level is an event-driven state chart which computes set points for the lower-level continuous controllers. This upper controller is implemented using Stateflow^{tm}. The last part of the paper