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ScienceDirect

Energy Procedia 49 (2014) 2080 – 2089

Energy Procedia

SolarPACES 2013

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.

Selection and peer review by the scientific conference committee of SolarPACES 2013 under responsibility of PSE AG.
Final manuscript published as received without editorial corrections.
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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Selection and peer review by the scientific conference committee of SolarPACES 2013 under responsibility of PSE AG.
Final manuscript published as received without editorial corrections.
doi:10.1016/j.egypro.2014.03.220

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
DNI	Direct Normal Irradiation (W/m^2)
E	Exchange efficiency
L	Level (mm)
M	Inertia parameter (kg)
N	Number
O	Opening
Q	Heat Flux (W)
S	Heat surface (m^2)
T	Temperature (K)
V	Volume (m^3)
W	Electric Power (W)
c	Heat capacity(J/K)
k	Proportional gain
h	Specific enthalpy (J/kg/°C)
h	Heat coefficient (W/°C/m^2)
m	Mass (kg)
p	Pressure (Pa)
q	Flow rate (kg/s)
α	Steam fraction
λ	Fluid thermal conductivity (W/m/°C)
ρ	Density (kg/m^3)
η	Efficiency

Subscripts

EV	Evaporator
SH	Superheater
c	Cold or convection
cd	Condensation
d	Desuperheater
dc	Downcomer
ev	Evaporation
f	Feedwater
h	Hot or heliostat
l	Latent
$loss$	Loss
m	Massic or metal
oil	Oil
r	Riser
s	Steam
sat	Saturation
sd	steam under water level in the drum
t	Turbine or total
v	Volumic
w	Water

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™ 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™. The last part of the paper