Control of a concentrated solar thermal plant for heat production under various demand scenarios

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1. Introduction

Decarbonization of the industrial sector is a major challenge to reduce climate change. Thermal energy is one of the most consumed energy by industrial processes and is mainly provided by natural gas combustion. Concentrated Solar Thermal (CST) seems a relevant carbon-free alternative for industrial heat production, due to its high conversion efficiency [1].

In this paper, we present a control strategy designed to satisfy a heat demand with a small-scale CST plant equipped with three parabolic trough collectors, for a recoverable thermal power of 150 kW. The simplified architecture of this plant is given in Figure 1, while Table 1 describes the key variables.

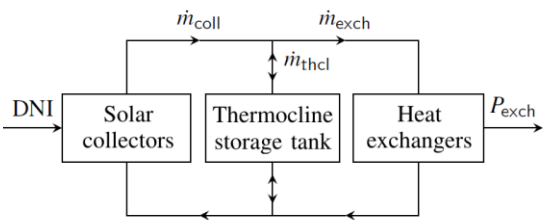

Fig. 1: Interactions between the three systems in the CST plant

Variable	Description
$\dot{m}_{coll}$	Mass flow inside the solar collectors
$\dot{m}_{thcl}$	Upward mass flow inside the thermocline tank
$\dot{m}_{exch}$	Mass flow inside the heat exchangers
P_{exch}	Transferred power through the heat exchangers
DNI	Direct Normal Irradiance

Tab. 1: Key variables involved in the CST plant operation

2. Control strategy description

The developed control strategy takes advantage of the storage system to adapt to DNI variations. The objective is to satisfy a heat demand by modifying the heat transfer fluid mass flow inside the thermocline tank $\dot{m}_{thcl}$. The implemented control strategy is based on Model-based Predictive Control (MPC). In our case, the control inputs are determined using an optimization algorithm which minimizes the deviation between the exchanged power P_{exch} and the heat demand P_{demand}, while respecting a minimum and maximum mass flow ($\dot{m}_{thcl}$ is positive when the storage is discharged and negative when it is charged). The nonlinear optimization problem solved at each iteration is formulated in Equation (1):

$$\min_{\dot{m}_{thcl}\in\mathbb{R}^n} \sqrt{\sum_{i=0}^{n-1}(P_{exch}(i) - P_{demand}(i))^2} \qquad (1)$$

$$\text{subject to} \quad -\dot{m}_{coll}(i) < \dot{m}_{thcl}(i) < \dot{m}_{max} - \dot{m}_{coll}(i), \quad \forall i \in [\![0, n-1]\!]$$

The exchanged power has to be determined as a function of $\dot{m}_{\mathrm{thcl}}$, which is achieved by modelling the temperature of the heat transfer fluid that circulates in the CST plant [2]. Furthermore, the mass flow inside the solar collectors $\dot{m}_{\mathrm{coll}}$ is calculated before the optimization starts to stabilize the collectors outlet temperature value around 300°C. The optimized mass flow is then applied to an accurate model of the thermocline tank [3] and the solar collectors [4] in order to simulate the CST plant's response to this control input.

3. Results of the control algorithm using various heat demands

We can assess the performance of this control strategy by taking into consideration two criteria: the deviation from the heat demand and the maximum overshoot. We decided to evaluate these criteria on three different heat demand scenarios. The first scenario is a constant heat demand at 30 kW. The second scenario is a batch heat demand which consists in 1h-long batches with a thermal power demand of 60 kW, followed by 1h with no thermal power required. The third scenario represents what would be a realistic heat demand for a paper treatment process [5], with a slowly varying heat demand during the day. The CST plant response to these scenarios was simulated on a clear-sky situation, as shown in Table 2.

Scenario	Deviation from the objective (kWh)	Maximum overshoot (%)
Constant heat demand	0.79	2.93
Batch heat demand	2.72	2.80
Realistic heat demand	1.10	4.90

Tab. 2: Performance of the control strategy under various heat demand scenarios

The control strategy manages to satisfy the heat demand with little deviation and limited overshoot. We can note that the strategy performs similarly for each heat demand scenario despite their specificities. Indeed, the realistic and constant heat demands are easier to satisfy because of the slow to no variation of the thermal power required, however, the batch heat demand features very high power ramps which are difficult to follow. The control strategy is equally reliable on these scenarios, and we can expect it to behave similarly on other heat demand scenarios given how it performs on the batch heat demand.

References

[1] A. K. Sharma, C. Sharma, S. C. Mullick, and T. C. Kandpal, 'Solar industrial process heating: A review', *Renew. Sustain. Energy Rev.*, vol. 78, pp. 124–137, Oct. 2017, doi: 10.1016/j.rser.2017.04.079.

[2] E. Girard, J. Eynard, S. Thil, and S. Grieu, 'Development and evaluation of a control oriented model to optimize industrial heat production of a parabolic through solar power plant', presented at the SolarPACES 2024, Rome, Italy, Oct. 08, 2024.

[3] J. F. Hoffmann, T. Fasquelle, V. Goetz, and X. Py, 'A thermocline thermal energy storage system with filler materials for concentrated solar power plants: Experimental data and numerical model sensitivity to different experimental tank scales', *Appl. Therm. Eng.*, vol. 100, pp. 753–761, May 2016, doi: 10.1016/j.applthermaleng.2016.01.110.

[4] T. Fasquelle, Q. Falcoz, P. Neveu, F. Lecat, and G. Flamant, 'A thermal model to predict the dynamic performances of parabolic trough lines', *Energy*, vol. 141, pp. 1187–1203, Dec. 2017, doi: 10.1016/j.energy.2017.09.063.

[5] A. Sandhaas, H. Kim, C. De Jesús Tabora, and N. Hartmann, 'Generation of Industrial Electricity and Heat Demand Profiles for Energy System Analysis', IAEE conference proceedings, pp. 1–14, 2022.