Modelling and control of a solar thermal power plant

Esko Juuso*

*University of Oulu, Department of Process and Environmental Engineering,
Control Engineering Laboratory, FI-90014 University of Oulu, P.O.Box 7300*

1 Introduction

Solar power plants should be designed to collect available thermal energy is in a usable form within the desired temperature range. This improves the overall system efficiency and reduces the demands placed on auxiliary equipments. In cloudy conditions, the collector field is maintained in a standby mode ready for full-scale operation when the intensity of the sunlight rises once again. Solar collector field is good test platform for various control methodologies. Lumped parameter models , which take the sun's position, field geometry, mirror reflectivity, solar radiation, and inlet oil temperature into account, have been developed for a solar collector field.

2 Objectives of the research

Over the years, numerous studies have been conducted in solar collector field producing extensive material and valuable experience on different control procedures. This wide source of information and experience on controlling can be analysed using a development and tuning environment. For diagnostical purposes, the simulator is extended by including additional features. The LE controller adjusted to operate in changing conditions by introducing an extended feedback approach where predicted load disturbances are compared with the present situation which is known by the controller

3 Results

All the experiments have been carried out in the Acurex Solar Collectors Field of the Plataforma Solar de Almeria located in the desert of Tabernas (Almeria), in the south of Spain. The Acurex field supplies thermal energy (1 MW) in form of hot oil to an electricity generation system or a Multi–Effect Desalination Plant. The solar field consists of parabolic-trough collectors. Control is achieved by means of varying the flow pumped through the pipes during the plant operation. In addition to this, the collector field status must be monitored to prevent potentially hazards situations, e.g. oil temperatures greater than 300 ^{o}C. The temperature increase in the field may rise upto 110 degrees. The daily operation is begun by circulating the oil in the field, and once the appropriate outlet temperature is achieved the valve to storage system (Figure 1) is open.

**E-mail: esko.juuso@oulu.fi*

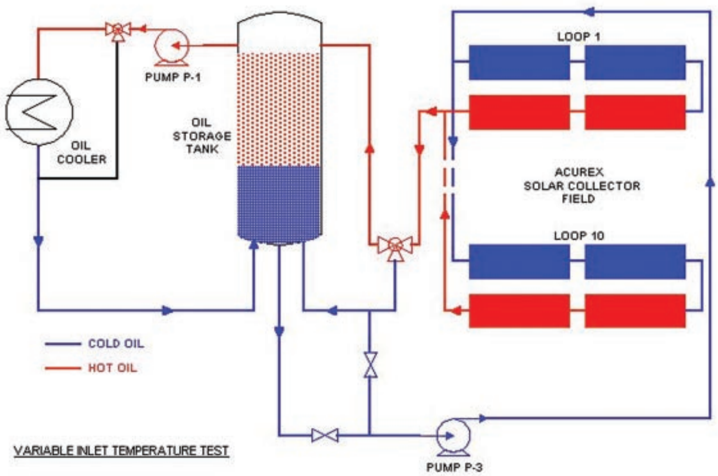

Figure 1 Layout of the Acurex solar collector field

3.1 Multilevel process control

The multilevel control system consists of a nonlinear LE controller with predefined adaptation models, some smart features for avoiding difficult operating conditions and a cascade controller for obtaining smooth operation. The multilevel control system consists of a nonlinear LE controller with predefined adaptation models, some smart features for avoiding difficult operating conditions and a cascade controller for obtaining smooth operation. The basic controller is a PI-type LE controller, is nonlinear and it can be represented by the function:

$$f_{6i}^{-1}(\Delta u_j) = K_P(i,j)\, f_{4j}^{-1}(\Delta e_j) + K_I(i,j)\, f_{3j}^{-1}(e_j) \quad (1)$$

The error Δe_j and the derivative of error Δe_j of the controlled variable j are mapped to the linguistic range by nonlinear scaling with nonlinear scaling. The change of control Δu_{ij} is scaled back to the real scale. The controller can be tuned by modifying the membership definitions and coefficients $K_p(i,j)$ and $K_I(i,j)$.

The adaptive scaling is based on the working point model: the scaled value of the effective solar irradiation and the temperature difference between inlet and outlet temperatures were used. In the normal working point (wp = 0), the irradiation, I_{eff}, and the temperature difference, T_{diff}, are on the same level. A high working point (wp > 0) means low T_{diff} compared to the irradiation level Ieff. Correspondingly, low working point (wp < 0) means high T_{diff} compared to the irradiation level Ieff. The operation condition controller changes the control surface of the basic LE controller by modifying membership definitions for the change in the control variable Δu_{ij}.

The predictive braking actions was developed for the large step changes. The asymmetrical action is for fine-tuning in cases where a precise set point tracking is required. The smart actions are aimed for avoiding too high temperatures, which are usually results of following cases: (1) fast changes of the inlet temperature, (2) fast temperature rises in the field, and (3) too high temperature difference between the inlet and the outlet. The main purpose is to avoid oscillatory conditions as delays make it difficult to damp oscillations with feedback control.

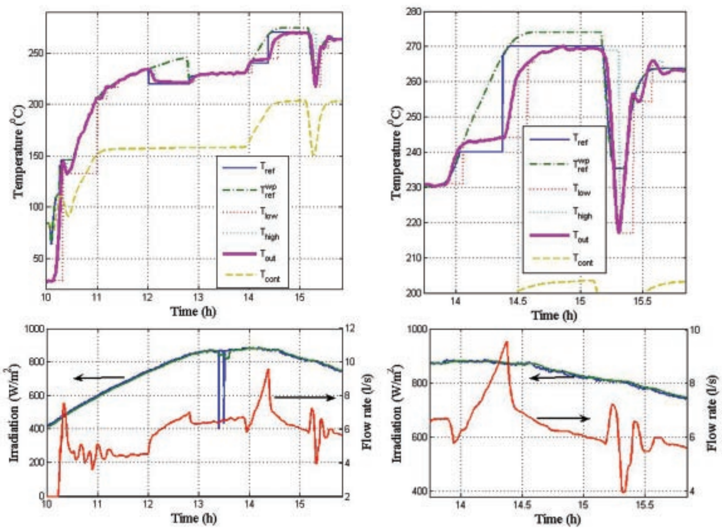

Figure 2 Test results of the Linguistic Equation Controller: temperatures, oil flow and irradiation

The control procedure with combined braking and unsymmetrical action provides a very fast and accurate start-up. The overshoot after the start-up is very small, but the response is slightly oscillatory if the difference between inlet and outlet temperatures is too steep. Set points could be based on the working point model throughout the day, i.e. the energy collection can be run on the basis of the chosen working point strategy. The only necessary limit is the upper limit of oil temperature. Difficult cloudy conditions were handled fairly well by the single equation controller.

The smart control actions are beneficial in smooth compensation of load disturbances without exceeding the safety limits of the collector system. Their tuning can be improved by distributed parameter models.

3.2 Energy collection

Earlier the working point model made the control surface steeper or flatter. This feature is increasingly important in the present controller as it affects the set point as well. The set point is reduced if the irradiation or the inlet temperature is staying on a lower level long time. Cascade control is used in the start-up to facilitate fast temperature increase without oscillatory behaviour. Similarly, the reduction of the set point is activated for load disturbances. In cloudy conditions the cascade control reduces considerably the overshoot after clouds.

The multilevel controller can handle efficiently even multiple disturbances. Adaptive set point procedure and feedforward features are essential for avoiding overheating. The new adaptive technique has reduced considerably temperature differences between collector loops. Efficient energy collection was achieved even in variable operating condition (Figure 3).

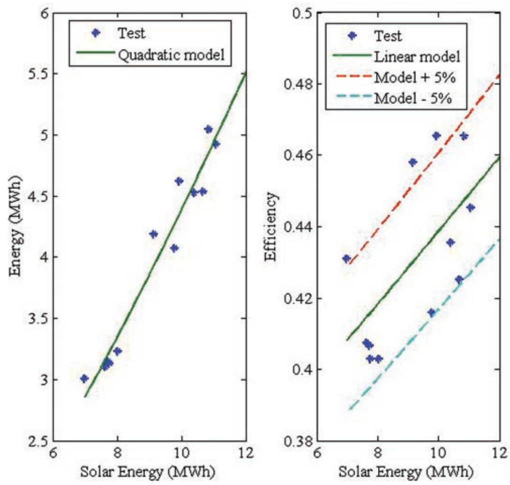

Figure 3 Results of the energy collection

Relevance of the research

Various nonlinear features are adapted to changing operating conditions with predefined adaptation techniques. Tuning with different lumped and distributed parameter models improve performance of the controllers. The new adaptive control technique has reduced considerably temperature differences between collector loops. Efficient energy collection was achieved even in variable operating condition.

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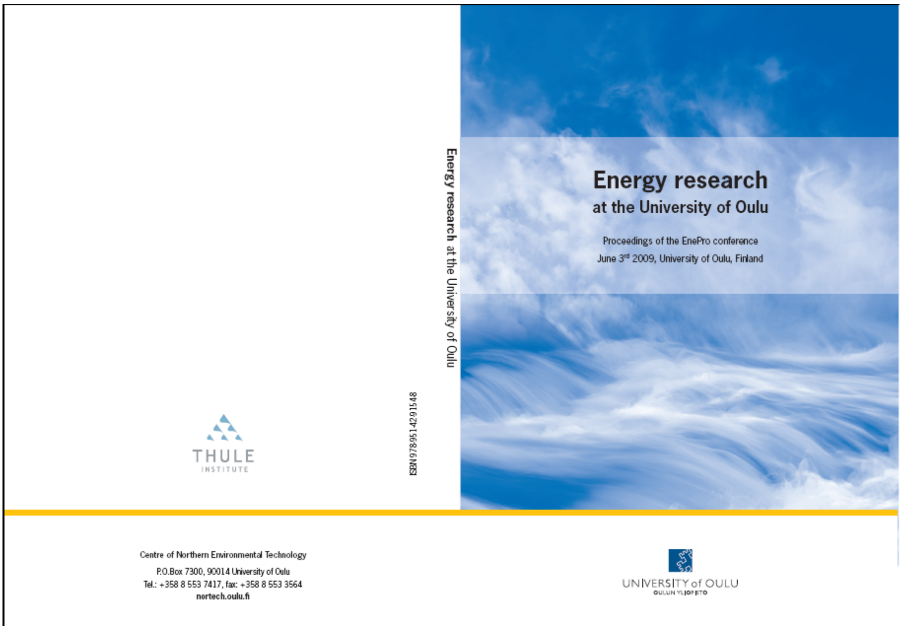

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