MODEL-BASED CONTROL STRATEGIES FOR AN EFFICIENT INTEGRATION OF SOLAR THERMAL PLANTS INTO DISTRICT HEATING GRIDS

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Abstract

The integration of solar thermal plants into district heating grids requires advanced control strategies in order to utilize the full potential in terms of efficiency and least operating effort. State-of-the-art control strategies cannot completely fulfill this since they are not able to consider the physical characteristics of the different components, nor do they take information on future conditions and requirements into account properly. A promising attempt for improvement is the application of model-based control strategies together with practicable forecasting methods for both the solar yield as well as the heat demand. This contribution will present the results of several projects performed on the development of suitable mathematical models, forecasting methods and control strategies relevant for the integration of solar thermal plants into district heating grids.

Keywords: model-based control strategies, forecasting methods, solar thermal plants, district heating grids

1. Introduction

Modern large-scale solar thermal plants are increasingly used as heat sources for heating grids. In urban environments, they are also often set up with local buffer storages and the possibility to directly supply local consumers with heat. In this specific case an additional bi-directional transfer station can be used which allows the supply of the local consumers with heat from the grid in case there is too little solar energy available. The most beneficial operating strategy of such a configuration first of all depends on the point of view: For the operator of the solar thermal plant, who is responsible for the supply of the local consumers, maximizing the on-site consumption will be most beneficial, since the prizes for heat fed into and taken from the heating grid typically differ significantly. For the operator of the heating grid, generally a different operating strategy would be most beneficial, since all other components and parties have to be taken into account. This contribution will focus on control strategies for an efficient integration from the point of view of the solar thermal plant operator, but also parts relevant for the district heating grid operator will be outlined.

The most important part of the solar thermal plant is the collector field. In the most general case, this solar collector field consists of several subfields connected in parallel that can differ in size. These differences in size have their origin in the optimization of the collector area under the local constraints of the place of installation which are often encountered in urban areas. In order to ensure an adequate flow distribution in the individual subfields, and to avoid exergy losses by mixing flows with different temperatures, the individual fields are typically equipped with adjustable balancing valves. These valves can either be adjusted manually for nominal operation or be driven by a servomotor in order to achieve an adequate flow distribution for every operating condition.

There are two major challenges to be faced when controlling such plants. The first challenge is to use the generated heat in an economically optimal way. The price for selling heat to the grid is typically lower than the price for buying it back, so an effective buffer management strategy is necessary which ensures the heat supply to the consumers while maximizing profits. The decision whether the heat currently generated should be stored in the buffer storage or be fed into the district heating grid determines the required feed temperature. When feeding into the grid, a minimum feed-in temperature must be provided by the plant; when feeding the local consumers via the buffer storage, a lower feed temperature is normally sufficient and thus a higher efficiency in the collectors can be obtained, a point that needs to be considered in the buffer management strategy.

The second challenge is to keep the outlet temperature of the solar collector field within certain boundaries and

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adjust it quickly regarding the mode of operation (store the heat in the buffer storage vs. feeding it into the district heating grid) even for fast changing ambient conditions. This is difficult because of several factors: first, there are delays between the control actions and the resulting outlet temperature changes, and the actuators are usually slow. Second, the outlet temperature depends on the accumulated influence of the solar irradiation during the transition time of the water through the collectors, thus requiring control strategies incorporating some kind of memory to obtain a good outlet temperature control performance.

To deal with these challenges, state-of-the-art control systems of solar thermal plants are often hierarchically structured. On a high-level basis, typically a set of rules defines the general mode of operation (e.g. feeding the heat into a district heating grid vs. storing it in the local buffer storage). On the low-level basis, control tasks such as controlling mass flows and temperatures are mainly handled separately for each subfield using simple linear PID controllers, which in some cases are enhanced by additional expert rules and, for example in the case of controlling the solar collector output temperatures, by energy balance calculations. On both control levels typically neither the non-linear and coupled characteristics of the different components are considered, nor is information on future conditions and requirements taken into account. Thus the default strategies applied on both levels usually do not yet utilize the full potential of modern solar thermal plants, mainly resulting in efficiency losses, even unused solar energy and increased operating efforts due to the need of frequent re-parametrization by the operators.

For both control levels, the most promising alternative approach would be the development and application of appropriate model-based control strategies combined with a good forecast of the expected heat generated by the plant and the heat demand of the local consumers.

Model-based control strategies base on mathematical models describing the fundamental static or dynamic characteristics of the different components and systems and thus allow an explicit consideration of the physical characteristics of the different components. In the case of high-level control, the specific method of model predictive control can also take information on future conditions and requirements into account. The models for most of the components and systems of interest available prior to the beginning of the work underlying this contribution were either too complex (used for comprehensive simulation studies) or too simple (static mass and energy balances). For this reason, the development of mathematical models suitable to serve as a basis for model-based control strategies represents a necessary part of the overall control development.

Furthermore, the available forecasting methods for solar yield and heat demand were in most of the cases mathematically by far too complicated, tailored for a specific application and very often not adaptive. Thus, they cannot serve as a general basis for model-based control strategies, which is why the development of general, simple and adaptive forecasting methods for the solar yield as well as the heat demand is another prerequisite for the final application of model-based control strategies.

This contribution presents a summary of the results of several projects performed on the development and validation of mathematical models suitable for model-based control strategies (section 2), forecasting methods for both the load demand as well as the solar yield (section 3) and control strategies relevant for the integration of solar thermal plants into district heating grids from the point of view of the solar thermal plant operator (section 4). Finally, section 5 sums up the results and draws a short conclusion.

2. Mathematical modelling

The modelling for the low-level control focusses on the correlation of pressure differences and mass flows in hydraulic components as well as the heat transfer, i.e. the temperature levels especially at the outlet of the components or systems as functions of the inlet temperature, ambient conditions and mass flows. The modelling for the high-level control focusses on heat storage and heat loss and aims at mathematically more simple models usable in optimization problems such as those formulated in model predictive control. Appropriate models for all relevant components in a solar thermal plant (buffer storage, collector fields and all hydraulic components for the heat distribution such as piping, pumps and valves) respectively control levels were developed, of which the model of the buffer storage as well as the solar circuit and its components are described exemplarily in this section.

2.1 Buffer storage

Buffer storages are used in order to decouple the occurrence of heat production from heat consumption at least at a certain degree. The mathematical modelling of buffer storages is primarily important for the high-level controller in order to estimate the available heat in the buffer within the next hours.

The modelling of buffer storages can be conducted in different levels of detail. In literature, models ranging from three-dimensional partial differential equations used for computational fluid dynamic (CFD) simulations, to single ordinary first-order differential equations can be found. In the next section three model of different detail are described: a detailed model primarily useful for simulation purposes (PDE model); the simplest possible model that is usually used for high-level, optimization-based control purposes (single integrator model); and a new, purpose-built linear hybrid model that combines the advantages of both for more accurate prediction results (hybrid model).

PDE model

A reasonable compromise of complexity and accuracy when considering a typical cylindrical buffer storage is to neglect the radial temperature dependency and assume a constant temperature at a specific axial (vertical) position. This assumption is supported by the usual mechanical construction of inlets aiming at a good radial distribution of entering fluids and thus minimal axial mixing. This leads to a mathematical model of one partial differential equation with only one spatially dependent variable (typically the temperature), where all relevant mechanisms of heat transfer are considered, e.g. (Cruickshank, 2009; Hemmer, 2014; Zlabinger, 2017). In simulations, the differential equation should preferably be solved implicitly in order to increase numerical stability and reduce computational effort. Typically, all model parameters can be determined from geometrical data and data sheets, but if they are not available or if the geometries are exceedingly complicated, it could be easier to determine some model parameters experimentally. This typically also would lead to an improved reproduction of the energy losses to the environment.

Fig. 1 shows results of an exemplary experimental verification of the model described in (Hemmer, 2014) performed with a commercially available buffer storage with a capacity of 1500 l. In the beginning, the upper third of the boiler got heated up to 70°C while the two lower thirds remained at ambient temperature. In the next step the lower part got heated up via an internal heat exchanger. In order to evaluate the simulation results, 12 vertically distributed temperature sensors have been installed. Despite the challenging setup the model describes the measured behaviour sufficiently well.

A model like this can be used for simulation purposes and even in a predictive high-level control not based on linear optimization. However, such controllers typically are computationally expensive and cannot rely on standard solvers. A simpler prediction model for the future available heat is thus required.

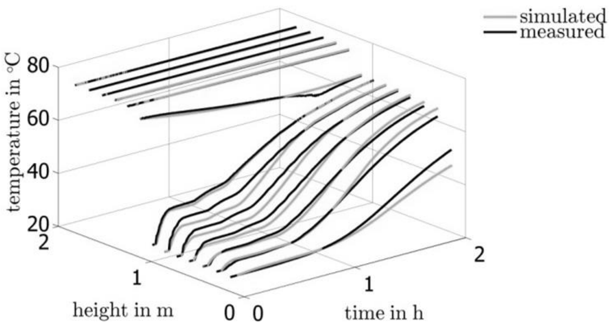

Fig. 1: Exemplary comparison of measured (black) and simulated (grey) vertical temperature distribution in a buffer storage while transferring heat via an internal heat exchanger in the lower third of the buffer.

Single integrator model

The single integrator model is the simplest approach for a linear model of a buffer storage and describes the dynamic behavior of the buffer storage on the basis of a simple energy balance

$$\frac{dE_{\mathrm{stor}}}{dt} = \sum \dot{E}_{\mathrm{in}} - \sum \dot{E}_{\mathrm{out}} \qquad \text{(eq. 1)}$$

with the stored energy as state variable E_{stor} and the in- $\dot{E}_{\mathrm{in}}$ and outgoing $\dot{E}_{\mathrm{out}}$ energy flows as inputs.

This model describes the energy content of typical cylindrical buffer storages sufficiently well to be used in model predictive control strategies with approximately constant inlet temperatures during the optimization horizon and comparatively quick charging and discharging cycles, where a detailed description of the losses is not crucial (Moser, 2017). But as soon as different, varying temperature levels or long-term operating cycles have to be taken into account, a more complex model has to be considered.

Hybrid model

In (Zlabinger, 2017) a more detailed but still linear approach is suggested, which is able to consider a finite number of different inlet temperatures and in- and outlets at different heights as well as all relevant mechanisms of heat transfer (convective heat input and output at predefined heights, axial heat conduction, environmental losses and natural convection). It is a hybrid, linear model that divides the buffer volume into different zones with constant mean temperatures and variable heights. The quantities of heat stored within these zones represent the continuous state variables of the system, and are described by simplified energy balances. The energy flows to the connected consumers and from the producers constitute the input variables. Depending on the heights of the zones in relation to the heights of the in- and outlets, different energy flows have to be considered. They are selected depending on additional discrete state variables that are used to distinguish between the different operating states. In the simplest form of the model, the consumers' return temperatures and the producers' feed temperatures are assumed to be constant, but through further case differentiation, varying inlet temperatures can be represented as well. Finally, the model can be described in the form of a mixed logical dynamic model (Bemporad and Morari, 1999), which is well-suited for the design of model predictive controllers for the high-level control as discussed in chapter 4.

2.2 Solar Circuit

The solar circuit in general consists of pipes, a pump, valves and several subfields, made up of multiple solar collectors, connected in parallel. It is connected to other hydraulic circuits via a heat exchanger. All these components have to be described through their thermal characteristics (heat transfer) as well as their hydraulic characteristics (correlation of pressure differences and mass flows) as described next.

Thermal characteristics

The thermal characteristics of pumps, valves and insulated pipes can be neglected for control purposes since no relevant heat transfer occurs. Only the thermal characteristics of the solar collector subfields are of major importance, for which several models of different levels of complexity already exist. On the one hand there exists a static model for the heat output of a solar collector based on a static energy balance, where the parameters are determined in a standardized collector test (EN12975) and can be found in the datasheet. This model is sometimes already used in today's control strategies in order to calculate a static feedforward control signal for the pump, and can be incorporated into solar yield forecasting methods (see section 3).

On the other hand there are more sophisticated dynamic models, such as models consisting of two coupled partial differential equations for the fluid and the absorber temperature of the collector, e.g. (Camacho et al., 2007a). Such more complicated models are often linearized in an operating point in order to obtain linear models. These linear models represent the dynamics of the outlet temperature of the collector field depending on the inlet temperature and the solar irradiation (Lemos et al., 2014) and can be used for model-based outlet temperature controllers. In several articles, the complicated models are used in combination with model-predictive controllers, e.g. (Camacho et al., 2007b; Lemos et al., 2014), but still more at an academic level or implemented in small-scale demo plants (Andrade et al., 2015).

Hydraulic characteristics

The hydraulic characteristics, namely the correlation of pressure differences and mass flows of the individual components in the solar circuit, play an important role for the low-level control. For pipes, valves and pumps simple models describing their static as well as their dynamic characteristics are summarized in (Unterberger et al., 2017). A turbulent flow regime can be assumed for all these components. When considering collector fields consisting of several large flat plate collectors this is different. The collector fields experience different flow regimes varying from laminar to turbulent as well as transition regimes between them. Thus, it is not sufficient to describe the correlation between pressure difference and mass flow through a purely quadratic equation. Another challenge in modelling the hydraulic characteristics of solar collector fields is the influence of the temperature. Due to the significant rise in temperature of a fluid flowing through a collector, its viscosity and density are highly affected. This effect even increases further when an anti-freeze mixture is used. This results in varying hydraulic resistance values depending on the temperature levels and temperature increases.

These challenges can be dealt with by expressing the pressure difference over a subfield Δp_{subf} as a combination of the pressure difference in a laminar flow regime Δp_{lam} and the pressure difference in a turbulent flow regime Δp_{turb}:

$$\Delta p_{\mathrm{subf}} = \Delta p_{\mathrm{lam}} + \Delta p_{\mathrm{turb}} \qquad \text{(eq. 2)}$$

The pressure difference in the laminar regime Δp_{lam} is based on the friction along a straight pipe of constant cross section described by the Darcy-Weisbach equation (Rouse, 1946). This is a linear correlation between the pressure difference Δp and the mass flow $\dot{m}$ for a certain fluid temperature T. The correlation depends on the pipe parameters diameter and length and is proportional to the temperature dependent kinematic viscosity of the fluid $\nu(T)$. The constant parameters, diameter and length can be combined in a constant parameter $R_{0,lam}$,which has to be determined experimentally for a specific temperature T_0:

$$p_{\mathrm{lam}} = \frac{\nu(T)}{\nu(T_0)} R_{0,\mathrm{lam}}\, \dot{m} \qquad \text{(eq. 3)}$$

The pressure difference in the turbulent regime Δp_{turb} is represented by an empirical formula usually used to describe the pressure drop due to an abrupt change in the pipe cross section as e.g. caused by a bezel. It is a correlation between the pressure difference and the square of the mass flow, with the constant parameter $R_{0,turb}$, experimentally determined for a specific temperature T_0, and the density of the fluid ρ:

$$p_{\mathrm{turb}} = \frac{\rho(T_0)}{\rho(T)} R_{0,\mathrm{turb}}\, \dot{m}^2 \qquad \text{(eq. 4)}$$

In practical applications, using the mean temperature between inlet and outlet of a solar collector usually provides a sufficiently accurate approximation of the correlation.

If a balancing valve is installed at the entry of the collector subfield, it is useful to describe the hydraulic characteristics of the collector subfield together with the balancing valve. In this case, both the laminar as well as the turbulent temperature independent coefficients ($R_{0,\mathrm{lam}}, R_{0,\mathrm{turb}}$) are modelled as a function of the valve position. This in turn allows calculating the valve position necessary to obtain a desired mass flow through the subfield given a specific pressure difference provided by the pump, which is useful for feedforward control strategies.

A comparison of the model with measurement data for a single collector subfield with an overall size of 172 m² is shown in Fig. 2 for stepwise changes of the plug position of a balancing valve.

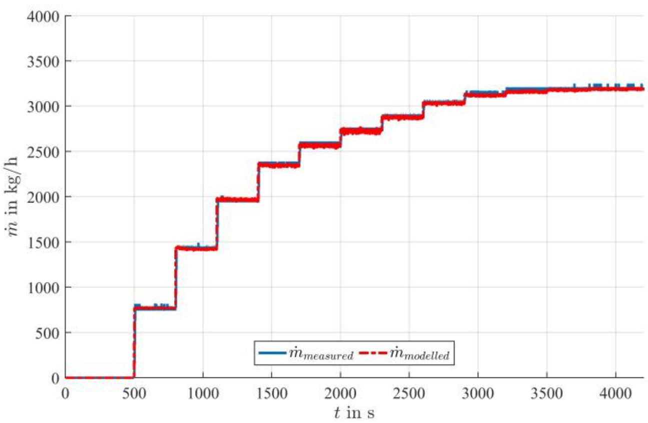

Fig. 2: Exemplary comparison of the measured (blue) and the modelled (red) mass flow through a solar collector field (172 m²) for stepwise changes of the plug position of a balancing valve at its inlet at a constant rotational speed of the pump.

3. Forecasts

The high-level controller, which is often called energy or load management system, of the solar thermal plant should incorporate forecasts for both the expectable solar yield and the expectable heat demand of the consumers in order to optimally plan generation, storage and consumption of heat.

Many different approaches for performing these forecasts can be found in literature, but almost all of them are highly academic and very complex. They are often tailor-made for specific configurations, require high computational effort and, due to their complexity, a comprehensive mathematical educational background of the implementing control engineers. Therefore, most of them are inappropriate to be widely used in practical implementations.

To be practical applicable, the forecasting methods first of all need to be general in order to cover a big variety of systems. Furthermore, the methods should be easy to implement and use little computational resources so that they can be integrated into the PLCs typically used for controlling solar thermal plants. Finally, the methods need to be able to adapt to varying conditions such as shading or changing consumer behavior. In this section, methods for predicting the future heat demand and the future solar yield are presented which fulfill these requirements and are thus usable in both solar thermal plants and district heating grids.

3.1 Forecasting method - heat demand

The method for forecasting heat demand presented in (Nigitz and Gölles, 2017) is based on the empirical analysis of the correlation between weather data and heat load data of several types of consumers. The analysis revealed that there exists an approximately linear correlation between load demand and ambient temperature and that there is a characteristic dependency of the heat load on the time of the day. Furthermore, it was also found that the individual days of the week do not have to be considered explicitly, but a distinction between working days and weekends/holidays turned out to be necessary.

The method predicts the heat demand of the consumers and corrects it by using the current prediction error as well as basic expert knowledge. The method itself is based on a linear regression model for each hour of the day describing the dependency of the heat demand on the ambient temperature. The parameters of the regression model are updated every hour taking into account the actual heat flow and the ambient temperature of the previous days, where only similar days are considered (work days or weekends/holidays). The only inputs necessary for the method are the measured heat flow supplied to the consumers and the predicted ambient temperature, provided e.g. from a weather service provider. This means that no parameterization is needed and no complex model of the connected buildings or the consumer behavior is necessary. Fig. 3 shows an exemplary forecast for the heat demand of a local consumer connected to the buffer storage of a thermal solar plant, compared to the actual load demand.

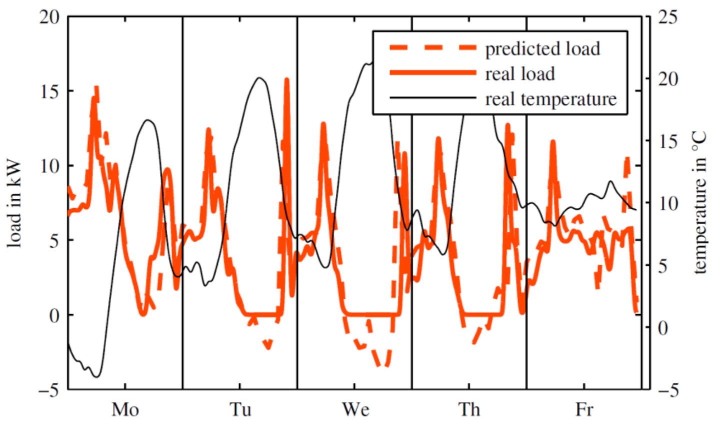

Fig. 3: Exemplary prediction of the load demand of an on-site consumer (connected load: 35 kW) compared to the actual (measured) load demand together with the (measured) ambient temperature for a representative work week.

3.2 Forecasting method - solar yield

The method developed to forecast the solar yield is based on an extensive analysis of weather data and measurement data from a large-scale solar thermal plant. The analysis showed that the static collector model (see section 2.2) with the model parameters from the datasheet, determined according to European Standard EN12975, does not directly lead to satisfying results but represents a suitable basis to forecast the solar yield. This is because the model parameters are only valid for stationary conditions in the laboratory and not for the dynamic conditions occurring in the daily operation. Furthermore, these model parameters would have to change over time because of polluted collector surfaces decreasing the optical efficiency, or because of the decay of materials leading to higher convective heat losses of the collector.

For this reason the method developed is based on the static collector model, but continuously estimates the collector parameters based on previous data. Like the method for forecasting the future heat demand, the method to forecast the future solar yield is based on linear regression models for each five minutes of the day describing the dependency of the solar yield on the ambient temperature, the global solar irradiation and the absorber temperature.

The parameters of the static collector model are adapted every five minutes, taking into account the past values of the measured solar yield, the measured ambient temperature as well as the measured global solar irradiation. By doing so, the pollution of the collector fields, the decay of the materials as well as the influence of local shading is automatically considered. In addition, no manual parameterization efforts or complex dynamic models are necessary. The only inputs necessary for the method are the measured solar yield and both the predicted and measured values for ambient temperature as well as global solar irradiation.

Fig. 4 shows an exemplary forecast of the solar yield for a sunny summer day of a subfield with 172 m² built in 2009, compared to the expected solar yield calculated with the static collector model with the parameters taken from the datasheet of the manufacturer as well as the actual measured solar yield. For this verification, real weather forecast data from the company *meteoblue AG* (https://www.meteoblue.com) was used, which provides weather information world-wide. This method will be extended by a correction approach in order to react on prediction deviations, which is for example necessary in case of very cloudy days.

It can be seen that the static model with the parameters taken from the datasheet would indicate the solar yield before 8 am as soon as global solar irradiation is predicted, not considering the heating up phase of the collector subfield. Furthermore, most of the time the static model is overestimating the solar yield. Only in the afternoon the prediction of the static collector model seems accurate. In fact this has its origin in the course of the predicted global solar irradiation which in the afternoon is below the measured one compensating the general overestimation of the collector efficiency. In contrast, the predicted solar yield resulting from the developed forecasting method with the parameters based on previous measurement data describes the real generated solar yield of the subfield throughout the day very well.

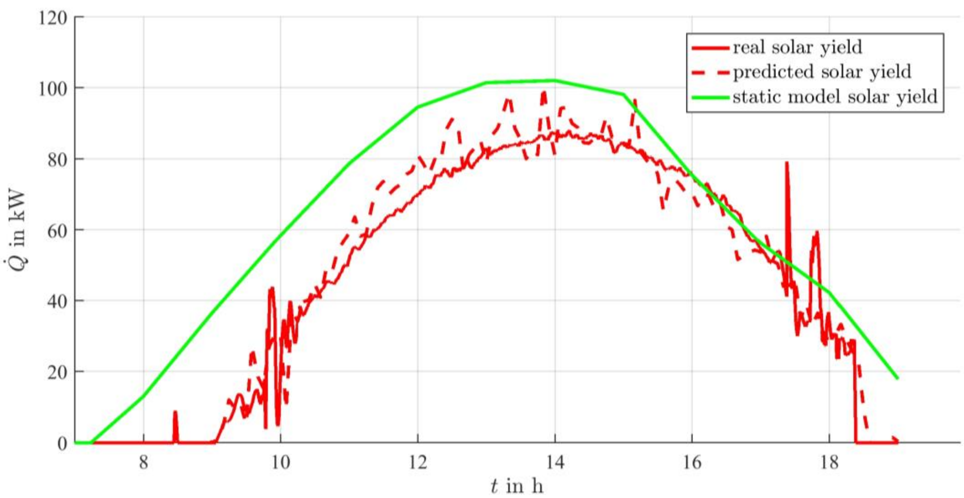

Fig. 4: Comparison between the measured solar yield, the predicted solar yield and the solar yield calculated with the static model and the parameters taken from the datasheet for a collector field of 172 m².

4. Control

The control of a solar thermal plant connected to a heating grid and local consumers must handle multiple aspects. Locally, a high-level controller must decide when to feed heat into the grid, when to store it locally and when to consume heat from the grid. A low-level controller must take care of temperature and mass flow control in the solar collectors, and of the heat distribution to and from the local buffer storage. At the heat transfer station, a grid controller must handle the feeding of heat into the grid or the transfer of heat from the grid to the local buffer storage. Such bidirectional heat transfer stations are still a matter of research, and often two transfer stations are operated in parallel, one for each task.

The different model-based controllers developed base on different methods from control theory. Fig. 5 shows the main idea of a model predictive controller used for the high-level control providing the reference values for all the underlying low-level controllers.

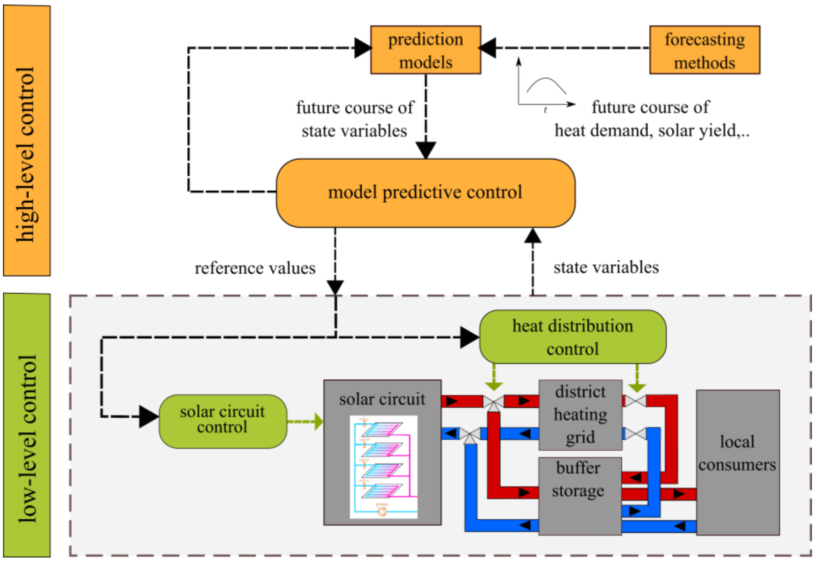

Fig. 5: Schematic overview of the interactions of the different control systems addressed

As an example for the different low-level controls to be considered, the control of the most important part, the solar circuit is discussed in more detail. The task of the low-level controller of the solar circuit is to realize the reference values given by the high-level control as efficiently as possible. In case of the solar collector circuit, this only influences the desired collector outlet temperature, which is different depending on the mode of operation of the plant - feeding the heat into the district heating grid requires a higher outlet temperature than storing it in the local buffer storage.

The desired outlet temperature of the solar circuit is realized by the model-based solar circuit control. It controls the pump in such a way that the mass flow necessary to achieve the desired outlet temperature is reached. In case there are motor-driven balancing valves installed in the subfields, these can be used to individually control the mass flows through the individual fields, and the controller has to adjust the valves appropriately. One possible control concept to accomplish this task will be described next, first for the case that controllable balancing valves exist in each collector subfield, then for the case where no motor-driven balancing valves exist.

In a first step, the mass flows through the N individual subfields ($\dot{m}_{1,\mathrm{des}}$ to $\dot{m}_{N,\mathrm{des}}$) necessary to achieve the desired outlet temperature $T_{\mathrm{out,des}}$ are calculated based on a thermal model of the solar collector field, e.g. the static collector model based on the energy balance mentioned in section 2. This requires the knowledge of (measured or predicted) influencing variables such as the global solar irradiation G, the ambient temperature T_{a} and the inlet temperature to the collector subfields T_{in}. The parameters of the thermal models for each subfield can be continuously estimated according to the forecasting method for the solar yield in order to consider shading, pollution of the collector surface or decay of materials.

In addition to this static calculation, the individual desired mass flows are continuously updated by a temperature controller. The temperature controller compares the current outlet temperatures of the individual subfields $T_{1,\mathrm{out}}$ to $T_{\mathrm{N,out}}$ with the desired outlet temperature $T_{\mathrm{out,des}}$. Based on this comparison, the desired mass flows calculated in the first step are either in- or decreased. In the simplest case, the temperature controller consists of very slowly adjusting PI controllers, but also more sophisticated, model-based control techniques could be used.

In the second step, the sum of the desired mass flows, together with the nominal positions of the valve plugs $\varphi^*{}_1$ to $\varphi^*{}_N$ are used to set the rotational speed of the pump n_P and, as a consequence, the differential pressure Δp_P. The nominal positions of the valve plugs are chosen between 80-100%, where 0% corresponds to a closed valve and 100% to an open valve. They should be chosen as high as possible in order to avoid unnecessarily increased pressure losses, but keeping in mind that controllability is reduced when the valve is opened too much because the valve will have less effect on the mass flow closer to the opened state.

The results of the two steps, the desired mass flows and the differential pressure of the pump, are used in a third step to determine the individual actual valve plug positions. In order to realize the adjusted desired mass flows, a feedforward controller for the valves is used. In this feedforward controller the valve positions φ_1 to φ_N necessary to accomplish the desired mass flows are determined based on the differential pressure provided by the pump and the hydraulic model of the solar collector subfield (see section 3). In the simplest case this feedforward control can be implemented neglecting the hydraulic couplings between the subfields, but even more extensive control techniques using graph-based algorithms, e.g. (Hassine and Eicker, 2014), could be used which take into account the hydraulic couplings by solving the equations simultaneously.

In case of larger model deviations, an additional slow controller could compare the actual valve positions (φ_1 to φ_N) with the nominal ones ($\varphi^*{}_1$ to $\varphi^*{}_N$) in order to adjust the rotational speed of the pump. Fig. 6 shows a schematic representation of the described strategy for the solar circuit control.

In case that there exist no motor-driven balancing valves in the solar circuit, the control strategy can be simplified to steps one (calculating the desired mass flows) and two (choosing the rotational speed of the pump), by adding a control loop comparing the overall outlet temperature of the solar circuit with the desired one, and adjusting the rotational speed of the pump accordingly.

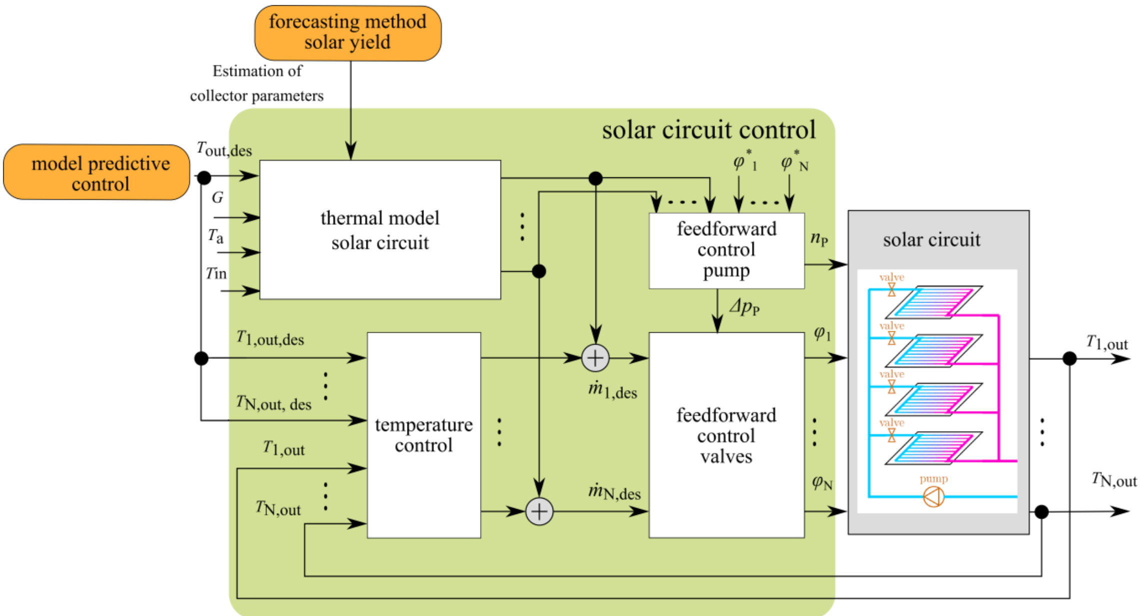

Fig. 6: Control approach for the low-level control of the solar circuit.

5. Conclusion and outlook

In order to efficiently integrate solar thermal plants into district heating grids challenges regarding the hydraulic control and the load management have to be dealt with. State-of-the-art control strategies cannot cope with these challenges in optimally since they are neither considering the non-linear and coupled characteristics occurring in such hydraulic systems, nor do they take into account future weather conditions and therefore cannot control the systems in a predictive manner. Instead, they can only react when a control deviation has already occurred. A promising approach for improvement is the application of model-based control strategies together with practicable forecasting methods for both the solar yield as well as the heat demand.

In this contribution models, forecasting methods as well as control strategies for solar thermal plants were presented exemplarily and verified with either measurement or simulation data, already showing good results. Some of the presented approaches such as the forecasting methods can serve as a basis for developing similar methods for the heating grid as well. Future investigations have to address the cooperation of the solar thermal plant with the district heating grid: for example the interactions of the high-level controllers in charge of the respective load management. This issue is relevant for all kinds of consumers also acting as producers, and is still a topic of current research.

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