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SMALL SCALE SOLAR THERMAL HEAT INTEGRATION IN DISTRICT HEATING NETWORKS

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Abstract

The first part of the paper describes the aspects of the mathematical modelling of decentralized integration of solar thermal in district heating networks. An attempt has been made to integrate the solar thermal energy with a simplified model of district heating network within the simulation environment INSEL.

The second part of the paper presents the results obtained with the new test bench implemented for decentralized integration of small-scale solar thermal plants. The designed test bench provides certain checks for applicability of substations to be used in conventional water based heating systems under different operational conditions of pressure and feed temperature.

1. INTRODUCTION

The utilization of renewable energy sources in urban areas is necessary to reduce the carbon footprint of cities. As energy demand for heating and hot water still dominates the total consumption in heating dominated climates, renewable heat production is a major issue. Centrally supplied district heating systems suffer from high distribution losses in the networks. Decentralized energy generation has the advantage to reduce the heat transport path and thus electrical pump consumption. It also allows a reduction of feed in temperature levels because of shorter distances and lower heat losses. Central heating plants often enter stand-by operation during the summer season. Building separated micro nets with own decentralized heating plants may minimize stand-by losses and present a good alternative to classic systems. The paper summarizes theoretical and practical aspects of decentralized heat supply systems into district heating networks.

2. DESCRIPTION OF THE SIMULATION MODEL

A simple integration of decentralised generated solar heat with the district heating network model

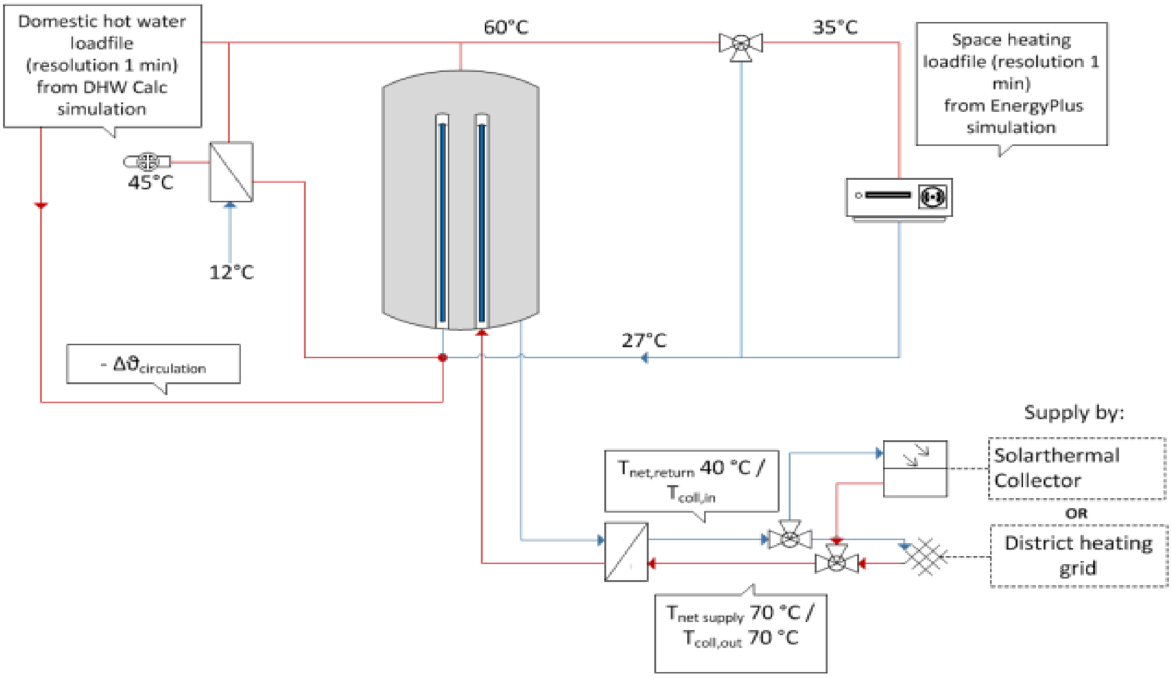

Fig. 1: Feed-in strategy of solar thermal heat

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is configured as connection of solar thermal plant to the heat storage tanks.

Design

The design of the implementation of the solar thermal heat is orientated at both, practical realization and available mathematical models in the integrated simulation environment INSEL. The stratified storage tank model in INSEL provides only the feed-in of one hot source and one cold source. Unlike real storage tanks, the feed in is always maintained at the right level to allow tank stratification. The solution for these feed-in limitations of the storage tank requires the mixing of space heating (SH) return line, domestic hot water (DHW) circulation and the return line of the DHW preparation of the external heat exchanger (red dot in scheme). The requirements of INSEL tank model are satisfied by simplifications of practical realizations.

The control strategy of switching between district heating and solar thermal plant is implemented according to the hot source requirements of INSEL tank model.

Control Strategy

The control strategy implemented in this investigation always ensures the peristent flow of resource between supply and demand. The control strategy to satisfy the heat demand of storage tanks depends upon the parameters of tank dimensions, allocated tank volume proportion per customer, available storage tank buffers for amount of discharge, lower levels of heat from solar thermal plant and mean distribution and duration of tapping events for corresponding operation times.

The external heat exchanger is switched to net supply if the total heat demand exceeds the solar supplied thermal power. Moreover, the model also switches to net supply in cases of lower tank temperatures below certain threshold temperature.

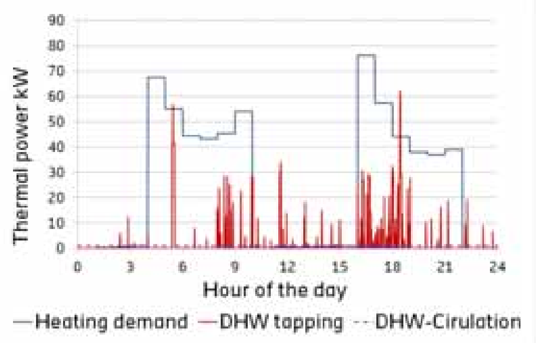

Fig. 2: Distribution of DHW tapping, circulation and space heating gains for a multifamily house (01. January – load files from EnergyPlus simulations and DHW-Calc)

On other hand, in summer seasons, the designed control strategy facilitates buffering of solar fraction of heat supply depending upon the demand.

Data Generation

The generated load profiles of SH demand and DHW preparation provide mathematical modelling of consumers heat demand from district heating networks. The SH data is obtained from the EnergyPlus simulations with reference to German insulation standard for buildings (KfW 100) and weather conditions of Stuttgart (South-West Germany).

The boundary conditions considered for the simulation of the multi-family house (MFH) and single family house (SFH) are listed in Table 1-3.

Table 1: General boundary conditions for MFH and SFH

Type	Quantity	Unit
Flow rate collector	*matched*	
DHW consumption (45°C)	*60*	$l\ person^{-1}\ day^{-1}$
German Insulation Standard	*KfW 100*	

Table 2: Boundary conditions of simulation MFH

Type	Quantity	Unit
Apartments (units)	*10*	
Habitable area	*1070*	m^2
Specific collector plane	*2.4*	$m^2 unit^{-1}$

Table 3: Boundary conditions of simulation SFH

Type	Quantity	Unit
Apartments (units)	*1*	
Habitable area	*205*	m^2
Specific collector plane	*4.6*	$m^2 unit^{-1}$

A DHW-Calc tool from University of Kassel (Germany) is used to generate time series data of DHW tapping. It provides random tapping profiles depending upon number of tap connections and total amount of draw-off per flat for given day.

The partial-integral (PI) controllers used for mass flow control of the solar thermal plants limits the maximum time step to approximately one minute interval in order to avoid unmuted oscillations of the controller and to provide proper fit between set point parameters and controlled values.

Therefore, the required input data (SH, DHW) is designed in time resolution of one minute. The used data set of load files for a MFH is shown in Fig. 2. Figure 2 also shows the daily heat distribution during heating season. The heating demand (blue line) reaches values of 45 to 75 kW peak while the predicted draw off of DHW (red line) achieves magnitudes between 15 to 65 kW. DHW circulation illustrated in violet in Fig. 2 has a continuous value of 1 kW.

3. SIMULATION RESULTS

The aim of the integration of solar thermal heat into district heating networks is to achieve autarchy for a group of consumers from main net supply during summer season. The thermal autarchy of single consumers within the net aids establishing of main grid independent micro nets. Micro nets are autarchy of a group of connected consumers, which can only be realized if single plant autarchy of enough consumers of the established micro net in both quality and quantity is reached. An indicator for single plant autarchy is the solar fraction during summer period of the solar thermal plants.

Fig. 3 (MFH) and Fig. 4 (SFH) depict the daily amount of solar fraction for the simulated solar thermal plants and the net return line temperature (on the net side of the external heat exchangers).

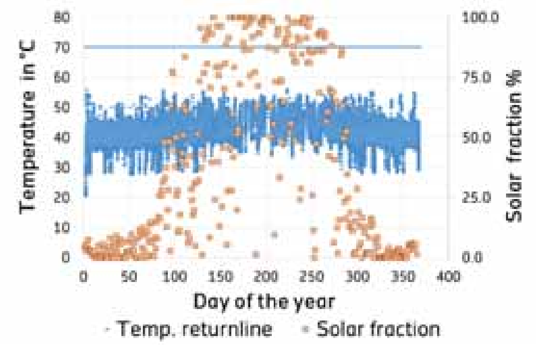

Fig. 3: Temperature of return line of district heating (DH), solar fraction of multi-family house (MFH)

Fig. 3 and 4 explains the data handling of the used static heat exchanger model. Heat exchange in the heat exchanger model of INSEL is calculated without considering thermal capacity of the exchanger. Therefore, a routine for handling simulation steps without mass flow have to be implemented. In the used simulation block these cases are solved by a simple algorithm that copies all inlet temperatures of the heat exchanger model to the outlet.

For long periods of non-operation of the heat exchanger this procedure is correct, but by simulation with dynamic changes of inputs this handling leads to figures like Fig. 3 and 4 (blue line). Whenever there is no mass flow through the heat exchanger the outlet temperature is set to the inlet temperature. In the figure it seems like there is a constant temperature of 70°C simulated. Essentially this line is discontinued, except cases when the solar fraction reaches 100%. (Fig. 4 during summer season).

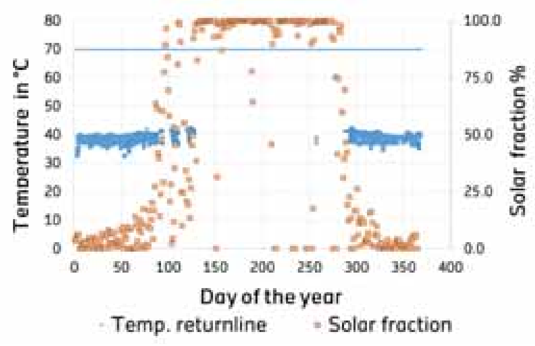

Fig. 4: Temperature of return line of district heating (DH), solar fraction of single family house (SFH)

Fig. 3 and 4 show the distribution of the solar fraction throughout one year (yellow dots). The temperatures of the return line of the DH is plotted in blue. By comparing both diagrams it is observed that days with a solar fraction of 100 % are more often achieved for the SFH than for the MFH. This results in more continuous distribution of DHW tapping in the MFH compared to the SFH. A second reason for the lower solar fraction of the MFH is due to the comparatively small size of the storage tank installed at the MFH. In the SFH a 0.875 m^3 tank serves by 200 m^2 of habitable area, while in case of the MFH a 1.0 m^3 storage tank supplies 1070 m^2.

In Table 4 and 5 essential simulation results are listed. The main aim of these simulations is to focus on the feasibility of autarchy micro nets during summer seasons. With solar fractions achieved for the SFHs this condition is reached. MFH with their greater variability of simultaneous tapping and their lower values for solar fraction must always be connected within micro nets with an adequate number of SFHs to cover their heat demand.

Table 4: Simulation results for MFH

Type	Quantity	Unit
Apartments (units)	*10*	
Habitable area	*1070*	m^2
Specific collector plane	*2.4*	$m^2\ unit^{-1}$
Useful heat for solar plant	*495,6*	$kWh\ m^{-2}\ a^{-1}$

Table 5: Simulation results for SFH

Type	Quantity	Unit
Apartments (units)	*1*	
Habitable area	*201*	m^2
Specific collector plane	*4.6*	$m^2\ unit^{-1}$
Useful heat for solar plant	*533.6*	$kWh\ m^{-2}\ a^{-1}$

The simulation shows that autarchy is theoretically possible on micro-networks level if enough SFH prosumers are connected. However, adequate substations should be developed to transfer surplus heat to the grid. The transfer should be safe and efficient. All the prosumer substations described in the literature are of medium to large size. In the following section, one small-scale feed-in-only substation is described. It has been developed in the framework of a current EnEff:Wärme project.

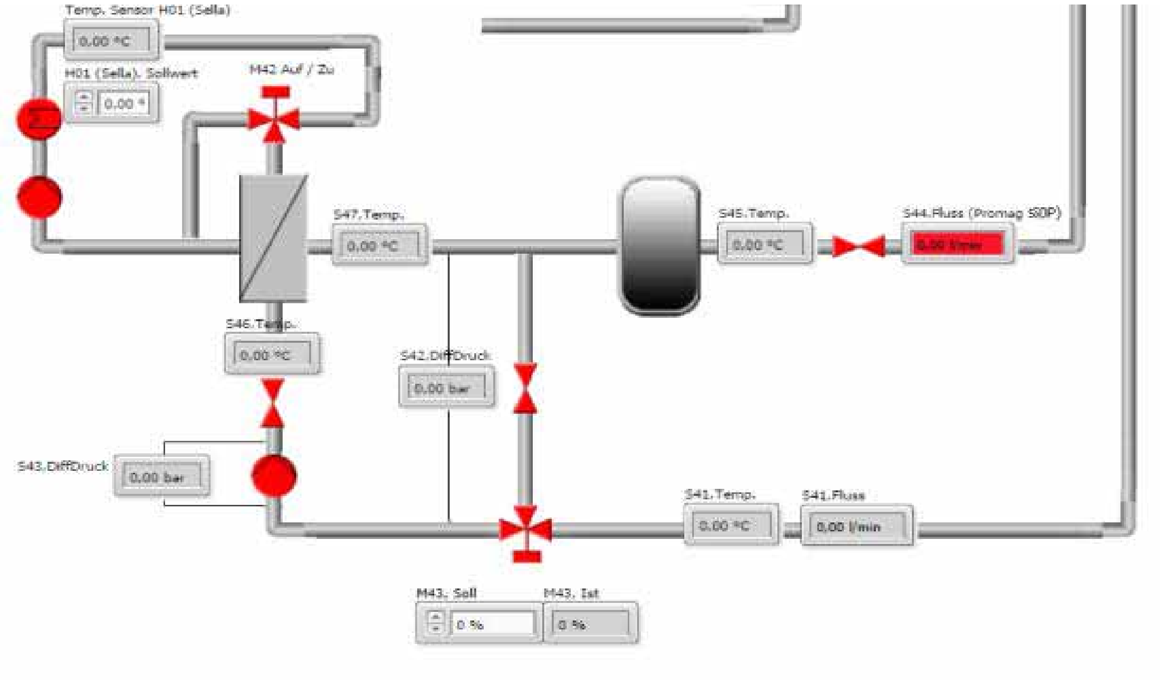

Fig.6: General layout of the 27kW feed-in substation

4. THE TEST BENCH FOR FEED-IN SUBSTATIONS

The test facility of Fig 5 was designed to develop and test heat substations under different operational conditions (differential pressure and feed temperature) [1].

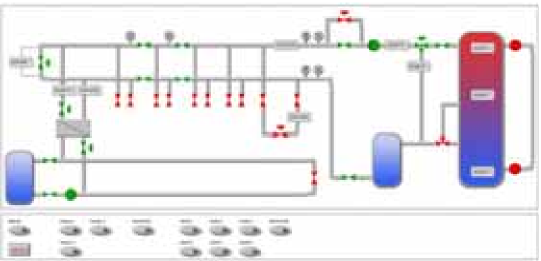

Fig. 5: Computer interface of the test bench

The first part of the facility has been already built to emulate a small heating network with six connections. Hot water is heated up electrically and stored in the buffer tank. The estimated storage heat capacity is 35kWh. The differential pressure is maintained by a circulation pump with PI-controlled speed. The final hot water temperature is controlled by 3-way mixing valve. Different valves are used along the supply and return line to simulate different pressure levels within the network.

The test object(s) can be connected close to measurement point for differential pressure or even closer to the pump. The cooling of the test objects is provided by a separate sub-network, which is cooled by a fan coil. Differential pressure up to 3.0bar and supply temperatures up to 100°C can be reached. The test rig is designed for small stations with up to 50kW transfer capacity and the expected flow rate does not exceed 4m^3/h.

The feed-in return→flow principle is challenging from a hydraulic point of view. In the few works found about this kind of integration, such as [2], the hydraulic aspect remains unexplored. Measurements of installed substations have not been published yet. A layout of the first substation being built to feed-in solar heated water into the network is shown in Fig.6.

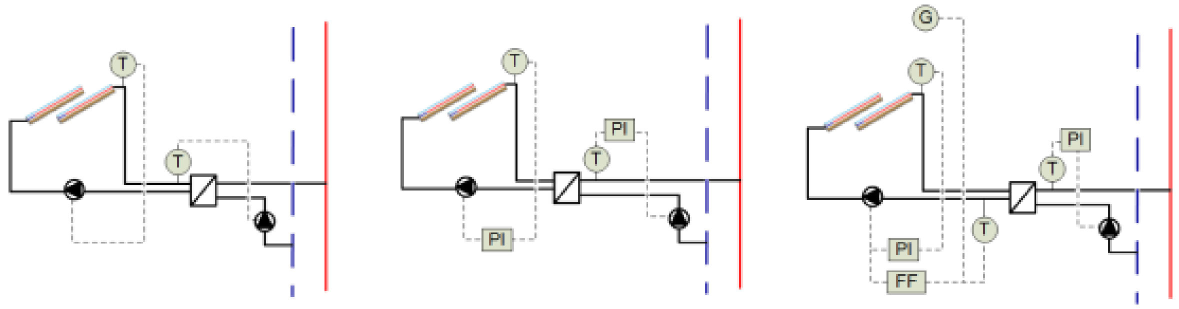

Fig 7: The control algorithms

The station is equipped with a transmitter for bidirectional flow, several valves and temperature sensors. Two pressure transmitters allow the control of the pressure difference between supply and return line. The solar loop is emulated through a 27kW electric heater as shown in the top left side of Fig.6.

5. SUBSTATION CONTROL

The control of the feed-in flow is challenging regarding two factors. First, the sun- which is the energy source in our case- has an intermittent and uncontrollable radiation course. Second, the network generally requires a certain supply temperature that should be considered and –in the same time- has highly changing dynamics due to the aperiodic operation of other distributed consumer valves. The pressure profile along the network changes depending on the demand of other substations. The prosumer control has to cope with such variations while providing the desired feed-in temperature. The three basic control algorithms shown in Fig7 are currently being implemented and tested in the bench. The bypass in the feed-in loop is not presented for clarity. In the left hand side, both feed-in and solar pump are ON/OFF controlled. In the second case PI control is applied to match the temperature requirements of the network. In the third substation, a feedforward FF term is added to the solar loop PI controller inorder to cancel disturbances in the return temperature and solar radiation.

6. MEASURMENT RESULTS

The first control scheme was implemented within the 27kW substation after fixing nominal flows for both solar and feed-in side by adjusting the valve apertures. The measurements are shown in Fig. 8. The return temperature of the network is held around 52°C where the solar supply temperature is varying between 60 and 87°C. At 79s the feed-in pump is started after having reached 70°C in the heat exchanger. The initially colder water in the feed line is heated gradually before feeding is interrupted due to the low temperature (<70°C). Later, the pump is operated again depending on the heat exchanger temperature. The feed-in temperature reaches the desired supply value and clearly reproduces the variations in the solar loop with an offset time of approx. 50s.

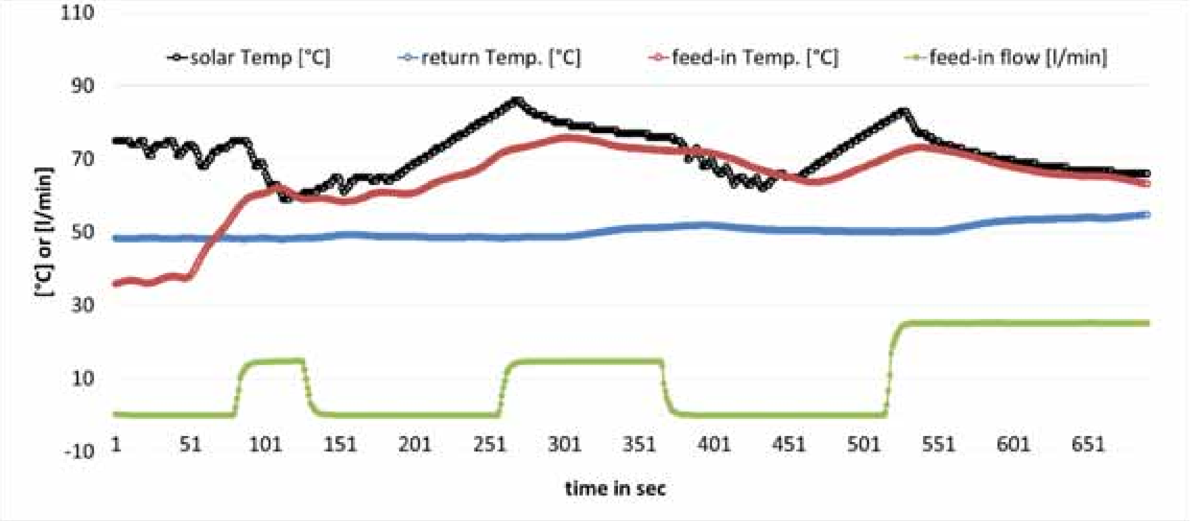

Fig.8 Measurement diagram

It is expected to have a damped feed-in temperature course using the PI and FF control. This has to be demonstrated under different radiation conditions.

7. OUTLOOK

The future scope of modelling is to design suitable solar thermal plants for 24 individual consumers. These models will be integrated into the detailed network model which accounts for the heat generation and consumption part of the district heating. The comparative studies for network models with and without solar thermal assistance can also be investigated. The direct feed-in strategies into the network can be analysed after evaluating the modelling of heat distribution network in INSEL. The remaining control schemes presented in Fig7 will be implemented to enhance the feed-in temperature course. A circulation pipe will also be added to avoid cold water streams during start-up. Further substations setups with positive displacement pumps are under development.

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