Sensible heat storage in district heating networks: a novel control strategy using the network as storage

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Abstract

District heating (DH) networks distribute heat generated at one or many heating plants to groups of buildings in order to cover their space heating and domestic hot water needs. The fact that consumers' peak heating loads are often occurring at the same time leads to a peak in heat generation. Additional peak boilers, usually operating with fossil fuels at high costs, are traditionally used to compensate peak demands for few hours.
As an alternative, by considering the water volume contained in the DH network piping, the network itself can be assimilated to large storage units and used effectively for peak reduction purposes. But even if this effect is known by district heating network operators, it is not applied systematically. Therefore a control technique is proposed and assessed by using simulation methods in this paper. The district heating network of Altenmarkt im Pongau (Austria) is modeled in the simulation environment Modelica/Dymola, using the standard library Modelica Fluid [2] and the DistrictHeatingLib developed at the Austrian Institute of Technology (AIT). Network simulations are performed to assess the impact of the proposed strategy. The results show a potential reduction of 15% of the daily peaks with an increase in heat losses of 0.3% compared to the reference scenario.

1. Introduction

Short term storage approach is considered to shift in time the peak demand. The aim of the paper is to propose an appropriate control strategy for using the pipe volume of the DH network as a sensible heat storage and to assess the impact of this strategy on the network operation.
The network of Altenmarkt im Pongau (Austria) is considered as case study. Heat generation is ensured by three boilers classified as base load, medium load and peak load boilers. The base load is covered by a biomass heating boiler coupled to an ORC-process for electricity generation. The medium load boiler is a biomass heating plant, and the peak load is covered by a boiler fired with fossil fuel. The average yearly supply and return temperature for the year 2009 were 95°C and 55°C respectively. 198 consumers were connected to the network in 2009, with an overall installed capacity of about $10MW$. The main supply line of the network has an overall length of approximately $10.3km$.

2. Modeling of the DH network and standard control strategy

The detailed model of the DH network computing the dynamic or steady-state response was developed in Modelica [6], based on existing models of the Modelica Fluid library [2] and on the DistrictHeatingLib developed at AIT. This includes models of substations and predefined pipes based on the Modelica Fluid specifications. The implementation of the DH control system uses components of the Modelica Standard Library. The choice of the simulation environment for DH analysis is assessed and reported in [1]. The thermal behaviour of the DH network is validated based on monitoring data from 2009.
As shown in Figure 1, the existing control system is made by two independent loops, the control variable being the network supply temperature in one loop and the pressure drop between supply and return line in the other loop. Considering the substation with the lowest pressure drop between supply and return line, the rotational speed of the network pump is adjusted in order to follow the setpoint defined as a minimum value of pressure drop to guarantee an adequate mass flow at this substation.

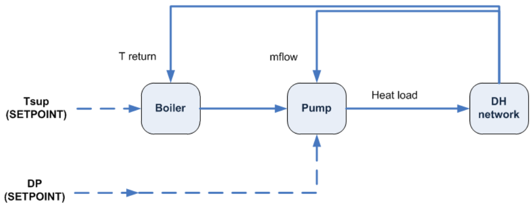

Figure 1. Standard control scheme used in the case study of Altenmarkt

3. DH as a storage: methodology of the control strategy

The potential reduction of peaks in heat generation by using centralised and decentralised sensible storage units was already assessed in different studies ([4], [5] and [3]). Even if the strategy consisting in increasing the network supply temperature at different times of the day is already known by district heating network operators, no example is known where this would have been applied systematically, i.e. based on an automatic control algorithm. A novel control strategy for using the DH as a buffer was therefore developed. The heat capacity of the network C can be calculated as:

$$C = \sum_{i=1}^{N} \rho \cdot c_p \cdot L_i \cdot \pi \frac{D_i^2}{4} \qquad (1)$$

where L_i and D_i are respectively the length and the diameter of the N-segments forming the DH network, c_p and ρ are the heat capacity and the density of the heat medium.

By considering equation (1), the theoretical storage capacity of a small size DH network like the one of Altenmarkt (average pipes: DN150) is approximately $20kWh/km.K$. Given the relatively limited storage capacity, possible applications are restricted to hourly peak shaving.

The control strategy analysed consists in introducing an additional control loop considering the heat load as control variable. A controller was designed and implemented in the simulation environment to vary the supply temperature of the boiler (Figure 2). The controller acts on the supply temperature of the boiler accordingly to the difference between the heat load setpoint and the actual amount of heat delivered by the boiler. The setpoint is calculated out of the daily heat demand of the overall network in the time period considered, including the distribution heat losses. The assumption for the novel control strategy is based on the reliability of the weather forecast and/or on the prediction of the daily heating energy demand. The limiter is set with the lower limit of 95°C (minimum requirements for the supply temperature to the substations) and the upper limit of 115°C according to pipe design requirements.

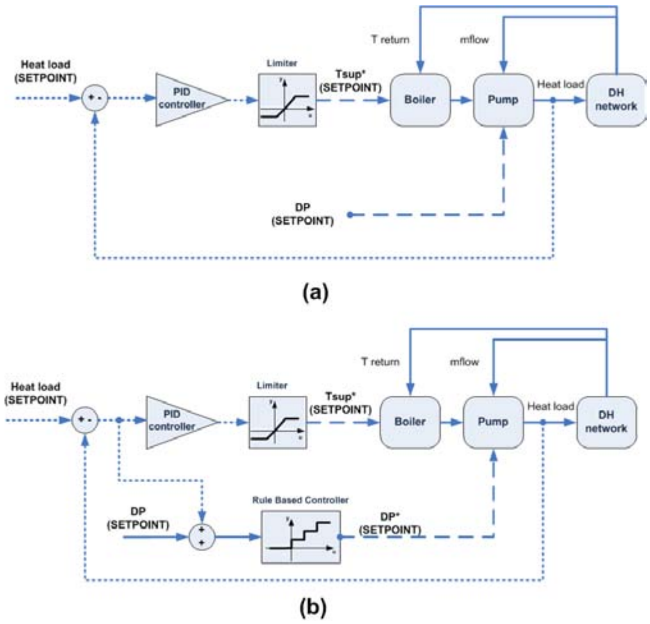

Figure 2. Proposed control scheme: DH network as storage

Moreover, according to limitations due to the boiler, a limiter is set with a maximum temperature derivative of $2K/min$.

Equation 2 describes the DH network energy balance.

$$\dot{Q}_{produced} = \dot{Q}_{consumed} + \dot{Q}_{losses} + \dot{Q}_{stored} \qquad (2)$$

Specifying the different terms leads to equation 3:

$$\begin{aligned} \dot{Q}_{produced} &= \dot{Q}_{consumed} + \\ &+(L_{sup} + L_{ret}) \cdot UA \cdot (\bar{T}_{avg} - T_{amb}) + \\ &+\dot{m}_{supply} \cdot c_p \cdot (\bar{T}_{supply} - T_{supply}) \qquad (3) \end{aligned}$$

where L_{sup} and L_{ret} are respectively the piping length of the supply and the return line, UA is the overall heat losses coefficient, $\bar{T}_{avg}$ is the average temperature between supply and return line and the $\bar{T}_{supply}$ is the increased supply temperature.

The energy balance shows that supply temperature increase represents sensible heat stored into the piping line of the network $\dot{Q}_{stored}$.

Heat production can also be expressed as:

$$\dot{Q}_{produced} = \dot{m}_{supply} \cdot c_p \cdot (T_{supply} - T_{return}) \qquad (4)$$

where $\dot{m}_{supply}$ is the mass flow through the pump, T_{supply} and T_{return} are respectively the supply and the return temperature through the boiler.

The implementation of an additional pressure drop rule-based control loop (Figure 2b) can be justified by looking at equation 4. As coupled effect, if T_{supply} is increased to $\bar{T}_{supply}$ then $\dot{m}_{supply}$ decreases since each substation can use the needed heat with a lower mass flow rate. Consequently $\dot{Q}_{stored}$ is being reduced while $\dot{m}_{supply}$ reduces.
In the specific case of Altenmarkt $\dot{m}_{supply}$ is around $15kg/s$ during the off-peak conditions (from 00:00 to 06:00). Considering also to the mass flow reduction due to supply temperature increase, $\dot{Q}_{stored}$ is limited to a value of $900kW$. Consequently to go beyond this threshold the mass flow rate and subsequently the pressure drop setpoint has to be increased (purpose of the rule-based controller).

4. Results

The effect of the control strategy in a typical winter day is presented in Figure 3. The reference scenario (no heat load controller), as well as the scenarios without DP controller (Figure 2a) and with the final controller (Figure 2b) are considered and a test case for the simulation is chosen (using monitoring data from 15 December 2009). For the scenarios without DP controller and the final controller, the loading phase starts at 2:00 and lasts for 3.5 hours.
Simulation results confirm the effects explained in section 3. In fact in the scenario without DP controller, supply temperature (see Figure 4) saturates the maximum allowed value, as explained by equation 3, but it is not possible to guarantee the heat load setpoint (4.8 MW) because of the limitation of $\dot{Q}_{stored}$ at $900kW$. Decrease of mass flow

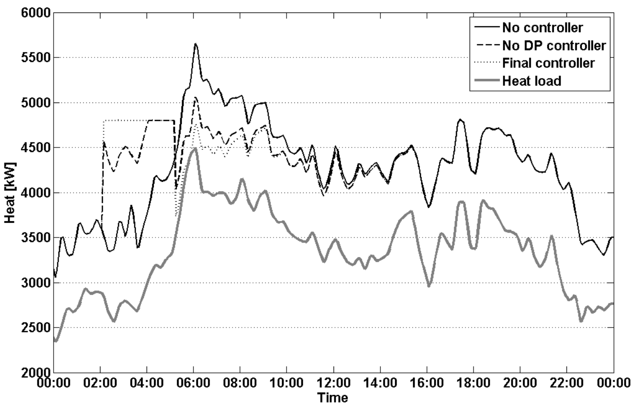

Figure 3. Heat production: reference scenario, no DP controller, final controller

rate can be pointed out in Figure 5 for the scenario without DP controller. On the other hand, the final pressure drop rule-based controller increases the mass flow rate and let the system reaching the heat load setpoint. In the case with

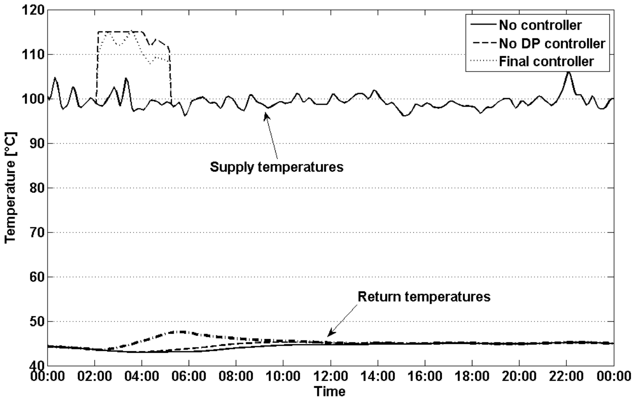

Figure 4. Supply and return temperature: reference scenario and different control strategies

the final controller, supply temperature within the charging phase has an average value of 110°C and the return temperature increases of about 5°C with respect to the reference case (Figure 4).

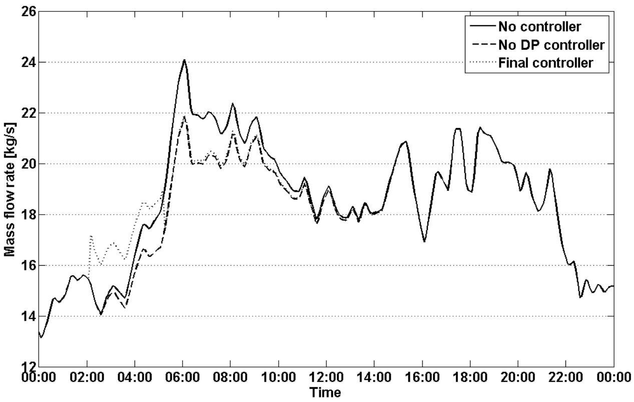

Figure 5. Mass flow rate: reference scenario, no DP controller, final controller

In order to derive an optimal strategy, a sensitivity analysis was performed by varying the starting time of the loading phase. Starting time varies from 00:00 to 04:00 and stop time is always fixed at 5:30 before the heat demand peak. Results are shown in Figure 6. As expected, the earlier the loading phase starts the greater is the peak reduction. However because of the limitation of the storage capacity, the peak reduction potential is saturated from 02:30. This means an increase in heat losses without beneficial effects in peak load reduction. Assessing the benefits of the peak

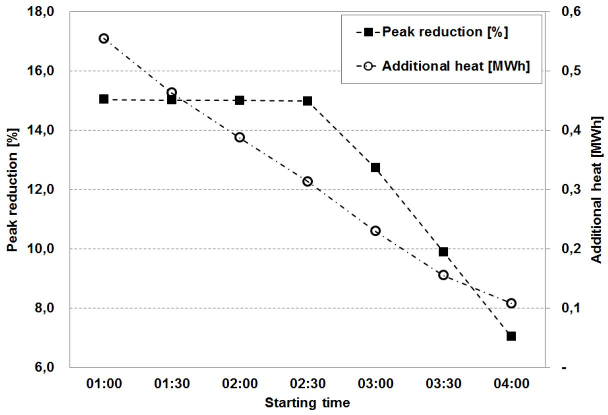

Figure 6. Starting time of the storage charging phase: sensitivity analysis

reduction (fuel cost reduction) and the costs for increasing the supply temperature, the optimum can be found with a starting time at 02:30.

5. Conclusions and future work

Applying the method described leads to a reduction up to 15% for the daily peaks and at the same time to an increase about 0.3% of distribution losses. The designed controller acts on varying the supply temperature of the boiler in order to keep the heat production as close as possible to the setpoint, resulting in an additional beneficial effect for the boiler which operates near to its design conditions.

The main advantage of this control strategy is the absence of additional costs. Based on simulation results and the plant performance in Altenmarkt, the proposed strategy enables a fuel costs reduction by 2% and CO2 emissions reduction by 20%. However, the storage capacity is limited by the DH network piping itself which is about 3.0MWh for the network considered, with an allowed range of supply temperature variation of 20°C˙

The proposed strategy will be implemented and assessed in the near future in the test case of Altenmarkt.

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