Development of a software system for optimal operation of heating networks with central solar plant

Thomas Oppelt[1], Thorsten Urbaneck[1], Sebastian Otto[2], Ingrid Heinrich[2], Andreas Schmidt[2], Thomas Göschel[3], Ulf Uhlig[3], and Holger Frey[3]

[1] Chemnitz University of Technology, Faculty of Mechanical Engineering, Professorship Technical Thermodynamics, 09107 Chemnitz, Germany

[2] Ingenieurbüro Last- und Energiemanagement LEM-Software, Nordplatz 6, 04105 Leipzig, Germany

[3] inetz GmbH, Augustusburger Straße 1, 09111 Chemnitz, Germany

Abstract

More and more district heating systems contain a central solar thermal plant in addition to the conventional CHP plant as heat source. In most cases, a short-term thermal energy storage is applied for balancing load and heat generation. The optimal operation of such complex systems regarding operational costs, high share of renewable energy sources, supply safety, etc. is difficult due to mutual influences of the different components as well as fluctuating loads, solar gain and electricity prices. In a current research project, a new software system named *Heating Network Navigator* is developed which will help the operators of solar district heating systems to reach optimal operation. The approach of the project is to combine an intelligent deterministic optimization scheme based on a system model with predictive control using forecasts of network load, solar yield and electricity price. Based on current and historical measured data and forecasts for the boundary conditions, the *Heating Network Navigator* will generate suggestions for the process control system on when to charge and discharge the thermal energy storage, which set-point to define for the collector output temperature in matched-flow operation, etc. during the optimization horizon of several hours to some days.

Keywords: solar district heating, combined heat and power, optimization, operation software, forecasting

1. Background

Heating supply to buildings is an important point when striving for the reduction of primary energy demands and CO_2 emissions. Larger settlement areas, e.g. city centers or neighborhoods with multiple dwelling units, can be supplied CO_2-neutrally with heat only via district heating (DH) (BSW, 2007). Integrating solar thermal plants into such central heating supply systems is a promising approach for using the sun as a renewable energy source. Solar heat is often paired with combined heat and power plants (CHP). With short-term heat storage, achieved solar coverage rates mostly lie in the range from 10 % to 25 % (BSW, 2007).

In Germany and Austria, several solar district heating systems have been built during the last years. For example, the solar district heating system in the Brühl quarter at Chemnitz, Germany with a collector area of 2100 m² was put into operation in 2016 (Urbaneck et al., 2014; Shrestha et al., 2018).

In order to utilize the huge potential of solar thermal energy, a quarter-based approach seems to be favorable (quarter level in contrast to town level). By transfiguring the heat supply on quarter level, existing DH systems as existing e.g. in most of the large German cities can be adapted to conditions that have been changing during the last decades. These are i.a. declining heat demands due to building insulation and climate change as well as the claim for low primary energy factors with heat prices being competitive at the same time. Thus, the project "Heating network navigator – software for extensively optimizing the operation of heating networks on town and quarter level" being presented here spatially concentrates on heating systems for quarters where solar thermal systems are combined with CHP and a thermal energy storage (TES). The following system types are considered:

- Quarter heating systems within larger heating systems (e.g. Chemnitz Brühl system),
- small district heating systems for residential quarters,
- district heating systems for small towns and villages (common in Denmark and Austria).

Figure 1 shows the schematic configuration of such a quarter heating system with short-term storage for the example of Brühl, Chemnitz. This solar DH system is connected to the town level DH system and the CPH plant, but decoupled hydraulically from these and operated independently. The system components in a quarter heating system

doi:10.18086/eurosun2018.05.05 Available at http://proceedings.ises.org

create a complex structure of mutual influences:

- Quarter heating network:
  - requires a certain supply temperature, i.e. depending on the current load, the technical equipment of the buildings and heat losses in the network,
  - a return temperature results e.g. depending on load, supply temperature and building equipment;
- Solar thermal plant:
  - efficiency depends on the return temperature (from the network or storage), the required supply temperature (depending on required network supply temperature etc.) and the ambient conditions,
  - auxiliary energy demand (circulation pumps) depending on collector flow rate;
- CHP plant:
  - profitability depends on the fluctuating electricity price,
  - current electricity price is influenced by load and supply of renewable energy (especially wind and PV power) into the national power grid,
  - the flexibility of the CHP plant depends on the technology and operational mode (constant or variable power-to-heat ratio);
- TES:
  - link between the network, the solar plant and the CHP plant,
  - the storage capacity depends on the supply and return temperatures in the network and heat losses,
  - losses are influenced by the temperature level in the storage as well as ambient conditions,
  - stratification quality has an influence on the temperatures at the top (supply temperature) and the bottom (return temperature to collector field) of the storage

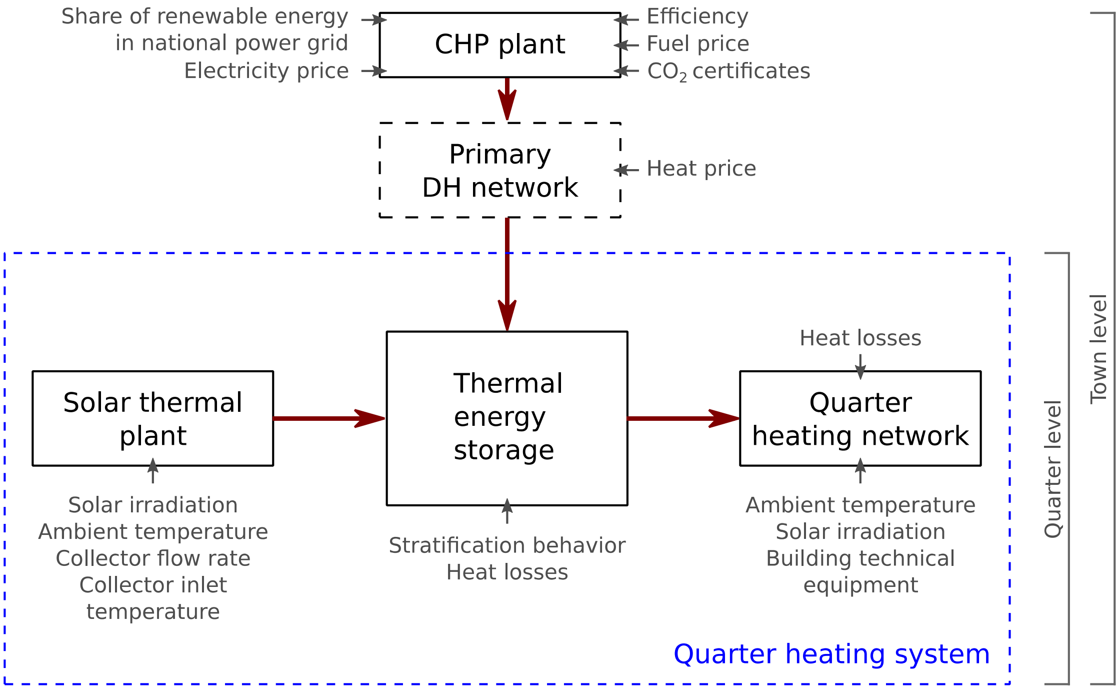

Figure 1: Scheme of a quarter heating system with solar plant, important influences on the system components (example system: Brühl, Chemnitz)

The manifold mutual influences between the system components, combined with external influences like economic boundary conditions and natural ambient conditions, make an optimal operation impossible to reach without special effort. For example, today solar plants often are controlled independently from the other components of the system or the storage is charged with CHP heat without taking into account the current heat demand and electricity price. It makes sense from the point of view of the operators as well as society to holistically optimize the system operation.

2. Project goals

The main goal of the research project which has been running since July 2017 is to develop a software system named *Heating Network Navigator* for heating network operators which will help them in reaching optimal system operation despite of difficult boundary conditions (integration of fluctuating renewable energy sources, varying electricity prices, etc.) and complex technical demands. This optimal operation can be characterized by the following target criteria:

- High share of renewable energy sources in heat supply,
- low operating costs,
- low primary energy factor in district heating (high product quality even under varying boundary conditions),
- security of supply.

The *Heating Network Navigator* is supposed to cover the following demands simultaneously (as far as possible):

- Optimal application of the short-term storage, e.g. avoid charging under unfavorable conditions for generation,
- best possible exploitation of solar irradiation, e.g. by minimizing the collector input temperature, avoiding unnecessarily high set-point values for the collector output temperature in matched-flow operation,
- minimizing the competition between solar thermal energy and CHP by avoiding unnecessary CHP charging of the storage based on forecasting solar yields on the one hand and using the storage capacity for CHP flexibility when low solar yields are expected on the other hand,
- minimizing the network supply temperature, thus reducing losses and providing good conditions for the solar system,
- maximizing the temperature difference in the network for maximizing the storage capacity, reaching a low collector input temperature and reducing the auxiliary energy demand for water circulation.

3. Approach

In order to reach holistic optimization of operation, the *Heating Network Navigator* should involve the following features:

- Intelligent deterministic optimization scheme (underlying model of the supply system as abstracted as possible and as detailed as required),
- predictive control algorithms (forecasting of load, solar yieldsolar and electricity price),
- learning software, e.g. autonomous adaption of the load forecast to changing boundary conditions like the occupancy rate in the quarter,
- adaptivity, e.g. flexibility facing different system configurations,
- integrated error identification, e.g. recognition of slow effects as calcification of heat exchangers.

Figure 2 schematically shows the planned integration of the *Heating Network Navigator* software system into the town quarter DH system (example: Brühl quarter, Chemnitz). The software receives measured data from the process control system, creates forecasts using mathematical models and generates an advice for the optimal operation based on the current measured data, the forecasts, time series (historical data) as well as “learned” information on previous operating conditions. This advice for a defined future horizon is sent to the process control system in order to be considered. Additionally, the *Heating Network Navigator* permanently compares operational data from past and present in order to detect errors in the system (error identification).

The mathematical-numerical optimization will be based on a model of the heating system which is included in the *Heating Network Navigator*. Based on a complex reference model, submodels for the different system components (e.g. storage, collector field) are developed during the project. These should reflect reality adequately on the one hand, but be as simple as possible on the other hand. Different types of models are applied:

- Physical models which are based on equations describing reality, e.g. energy conservation law, heat equation,
- blackbox models with mathematical regression equations which describe the correlation between input and output values without considering real physical effects,
- ANN models which determine output values from given input values by means of artificial neural networks (ANN).

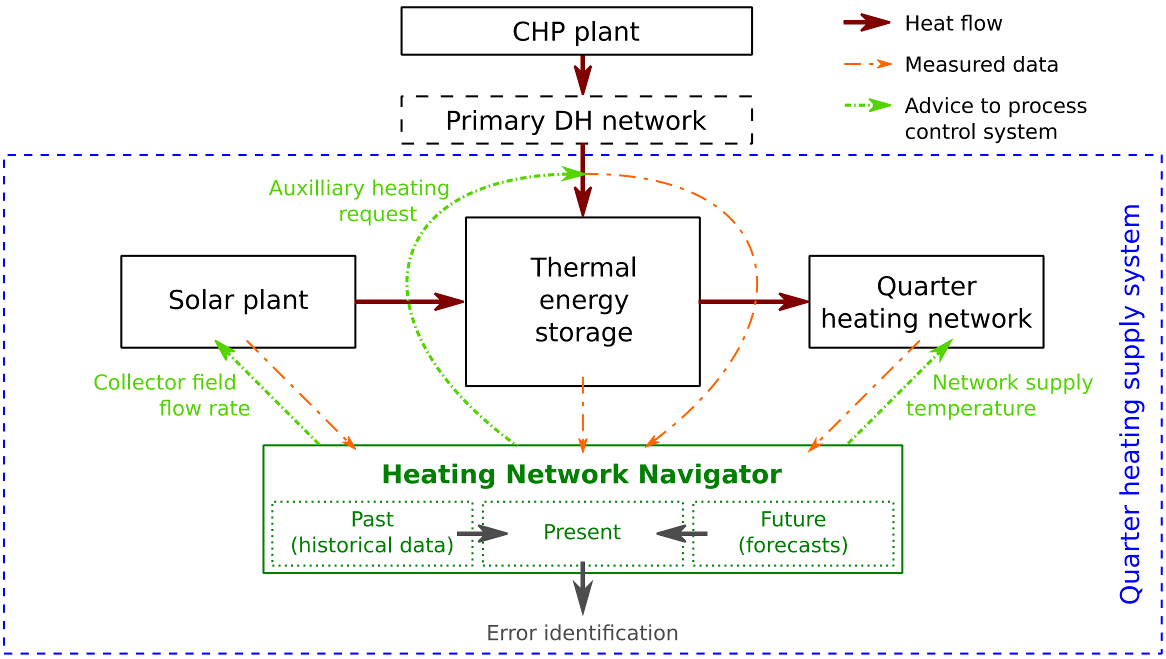

Fig. 2: Integration of the *Heating Network Navigator* into a quarter heating system

For each of the subsystems, one of these model types is especially suitable. For example, the TES requires a physical model because only such a model can represent the storage's complex transient stratification behavior with sufficient accuracy. Whereas, a blackbox model seems promising for the collector field and the load behavior of the heat customers is predestinated for applying an ANN model due to the stochastic effects.

Some of the authors where involved in the RenewIT European project (RenewIT, 2016; Salom et al., 2017) where metamodels (blackbox models) could be applied successfully for abstracting complex cooling supply systems. In the project presented here, the method established in the RenewIT project is developed further by combining blackbox models with physical models and ANN models. The abstracted overall model built from the different submodels is supposed to be applied during real operation for simulating different operation scenarios for the following period (optimization horizon about several hours to some days). Combined with the boundary conditions (current and historical measured data of the system, forecasted network load, solar irradiation/yield and electricity price), the *Heating Network Navigator* can thus generate control suggestions for the process control system which will lead to holistically optimal system operation. Control suggestions are the optimal operation parameters like when to charge or discharge the TES, which set-point temperature to specify for the matched flow operation of the collector field etc.

4. Project stages and outlook

During the project, the *Heating Network Navigator* will be pre-developed and tested. The project is subdivided into three stages of development:

1. Basic developments: In this first stage, simulation and forecasting models are developed and abstracted for application in the *Heating Network Navigator*.
2. Lab testing: The *Heating Network Navigator* is tested in a Hardware-in-the-loop (HIL) environment.
3. Real-life testing: Supported by the network operator inetz, the software system is tested in practice in the Brühl solar DH system at Chemnitz.

The project is running until end of 2019. Results will be published continuously on the project website (Oppelt and Urbaneck, 2018). At present, the project partners are in the first stage of development dealing with the models of the system components, the required forecasting algorithms and the optimization method.

Acknowledgements

The project underlying this paper is funded by the German Federal Ministry for Economic Affairs and Energy under the codes ZF4389101ST7/ZF4147602ST6 following a decision by the German parliament. Special thanks also go to the AiF Projekt GmbH for supporting the project. The sole responsibility for the report's contents lies with the authors.

References

BSW, 2007. GroSol – Studie zu großen Solarwärmeanlagen [GroSol – Study on large solar thermal systems]. Bundesverband Solarwirtschaft e.V.

Oppelt, T., Urbaneck, T., 2018: Project website Heating Network Navigator. http://www.wn-navi.de

RenewIT, 2016: RenewIT Project – Renewable Energy Simulation Tool for IT Data Centres. http://www.renewit-project.eu

Salom, J., Urbaneck, T., Oró, E., 2017. Advanced concepts for renewable energy supply of data centres. Delft: River Publishers. ISBN: 9788793519428.

Shrestha, N. Lal, Urbaneck, T., Oppelt, T., Platzer, B., Göschel T., Uhlig, U., Frey, H., 2018. Implementation of large solar thermal system into district heating network in Chemnitz (Germany). In: International Solar Energy Society (ed.): ISES Solar World Conference 2017 and the IEA SHC Solar Heating and Cooling, 322-332. - doi:10.18086/swc.2017.06.08.

Urbaneck, T., Oppelt, T., Platzer, B., Frey, H., Uhlig, U., Göschel, T., Zimmermann, D., Rabe, D., 2015. Solar district heating in East Germany – Transformation in a cogeneration dominated city. International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2014. In: Energy Procedia 70, 587-594. - doi:10.1016/j.egypro.2015.02.090.