A Modelica-Based Framework for District Heating Grid Simulation

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Abstract

The interdisciplinary modelling language Modelica is increasingly used in the design and evaluation of energy systems. Heat supply represents a considerable share of the global energy supply. Especially in European cities, district heating grids are often used and implemented for heat coverage. The increasing integration of renewable energies and the extension of existing grids require engineers to be able to analyze and evaluate the behavior of such grids, not only statically in certain operating conditions, but also dynamically to enable the representation of complex system interaction.

This paper shows and describes a new approach as to how Modelica models can be used to evaluate the dynamic behavior of district heating grids. It furthermore introduces a consistent framework to parameterize these models with GIS-data via the COM interface. The advantages of the shown approach compared to previously used static methods are shown with specific case studies.

Keywords: district heating grid, renewable energies, heat supply, GIS-data integration

1 Introduction

The development and planning of energy systems represents an increasing challenge for engineers. On the one hand, the goal of decarbonization in energy supply requires an increasing integration of volatile renewable energies. This volatility requires the integration of additional storage systems, ultimately resulting in the introduction of additional degrees of freedom and thus complexity, in power plant control.

On the other hand, the distribution of energy between production and consumers must be adapted to increasing decentralization and partial changes of exergy levels. This applies distinctly to district heating grids, which are particularly complex and widespread. The lowering of temperature levels within these grids leads to significantly reduced distribution losses. This temperature reduction also enables the integration of alternative heat sources such as solar thermal, which are not dependent on conventional combustion-based heat production.

For engineers, the challenge is both the design and evaluation of the central heating plants and the grid itself. The methods used up to present for this purpose have primarily included static calculations, of the system behavior for specific operating points. With this method the maximum load in winter is given priority and partial load cases are only considered subordinately. However, in order to be able to compare the system behavior with regard to energy efficiency, operating costs and ecological footprint, it is particularly important to consider these partial load cases. In addition, the integration of condition-based systems, such as storage, require a dynamic analysis approach rather than a static operating point analysis, based on system equilibrium.

Static grid calculation tools, such as STANET or BENTLEY, combine a clear, GIS-based grid representation with a calculation of the behavior of individual grid components, such as pipes, branches and house connections, based on extensive databases. These tools enable the calculation of temperature and pressure behavior in different grid areas for specific operating points on the basis of an iterative calculation approach. They also enable a clear grid and result representation on the basis of map data which facilitate an easy-to-understand result evaluation and interpretation. However, these tools do not have dynamic modeling capabilities.

Pressure and temperature are scalar physical states. This makes the use of the versatile modelling language Modelica ideal for adding dynamic considerations to existing calculation approaches. The approach of modelling district heating networks on the basis of Modelica has already been discussed in several research studies.

Soons et.al. 2014 implemented a complex district heating grid model including heat production, distribution and thermal building models with reduced complexity, based on Modelica, of a renewable energy building campus. The study considered temperature losses within the grid as well as resultant pressure drops depending on pipe friction. Schwan, et.al. 2014 implemented a Modelica model of a small rural town center with complex building models, district heating grid piping and renewable heat production based on the

Green Building library models. Hägg 2016 adapted available pipe models of the Modelica Standard Library (MSL) by replacing the finite volume method with a spatial distribution operator approach. Schweiger, et.al. 2017 implemented a Python-based framework to automatically generate a district heating grid model based on Modelon's Thermal Power Library. The master thesis of Hermansson et.al. 2017 describes a framework using Matlab to automate the data processing, modelling and simulation of Modelica district heating models.

All these approaches and studies already address a wide range of required toolsets and simulation models which engineers require to analyze and evaluate district heating grids in a dynamic way. The models and methods are mainly based on research work at universities and associated companies. However, planners and engineers involved in the practical implementation of such district heating networks require a uniform toolset based on standard planning tools and databases as well as a uniform presentation of the results of planning-specific parameters. The approach presented here enables the automated transfer of data from standardized district heating network simulation tools, such as STANET and BENTLEY, using standard MS Office products and the COM interface. In this way the often 5,000+ parameters for the modelling of a grid can easily be gathered, transferred and written into the model. In addition, the results obtained from the model can be fed back into the existing evaluation procedures.

2 Modelling Approach

Simulation models of hydraulic grids are comparatively easy to implement compared to complex power plant systems. The number of necessary model components is manageable. However, the size and complexity of a heating grid requires an overall model with a multitude of equal model components which are each defined by a multitude of parameters. This aspect characterizes the actual challenge in dynamic modelling.

Within this work a Modelica-based library of grid components has been implemented with the following six components:

- Pipeline
- Heating plant
- Grid node
- House connection station
- Pipe branch
- Pipe junction

The pipeline is the most important element of such a library. This model component describes the heat loss over the insulation ($\dot{Q}_{loss}$) in the flow and return pipes of individual grid sections as described in equation 1:

$$\dot{Q}_{loss} = \Delta Q_{insulation} \cdot l_{pipe} \cdot (T_{med} - T_{ground}) \quad (1)$$

The model also calculates the individual pressure drop (Δp) of a pipe depending on pipe roughness (2), pipe bends (3) as well as other fittings (4). Furthermore, it identifies pressure losses due to geodetic elevation differences (5).

$$\Delta p_{rough} = \lambda_{pipe} \cdot l_{pipe} \cdot \rho_{med} \cdot \frac{v_{pipe}^2}{2 \cdot d_{i,pipe}} \quad (2)$$

$$\Delta p_{bends} = \zeta_{pipe} \cdot l_{pipe} \cdot \rho_{med} \cdot \frac{v_{pipe}^2}{2} \quad (3)$$

$$\Delta p_{fittings} = \sum \Delta p_{element} \quad (4)$$

$$\Delta p_{geo} = \rho_{med} \cdot g \cdot \Delta z \quad (5)$$

The sum of these elements characterizes the total pressure drop within a pipeline. The gradient dependent, absolute pressure losses of a pipe are almost compensated between flow and return (i.e. only the difference between temperature-specific densities of the fluidic medium (ρ_{med}), cause a pressure drop).

The main pressure loss in a pipeline is dependent of the pipe friction (i.e. 90% plus in horizontal pipes). This pipe friction is highly reliant on the type of stream, i.e. laminar or turbulent in a smooth or rough pipe. To identify the stream type, the pipe friction coefficient (λ_{pipe}) is calculated based on Reynolds number (Re), includes the dynamic viscosity coefficient (η_{med}) as well as the roughness coefficient (k_{pipe}) and the pipe diameter ($d_{i,pipe}$).

$$Re = \frac{v_{pipe} \cdot d_{i,pipe} \cdot \rho_{med}}{\eta_{med}} \quad (6)$$

The Reynolds number is thus used as an indicator for the stream type. If the Reynolds number is smaller than 2,300, the stream type is defined as laminar.

$$\lambda_{pipe,lam} = \frac{64}{Re} \quad (7)$$

A Reynolds number between 2,300 and 100,000 indicates a turbulent stream type for a smooth pipe.

$$\lambda_{pipe,turb,smooth} = \frac{0.3164}{\sqrt[4]{Re}} \quad (8)$$

Any higher Reynolds number than 100,000 represents turbulent stream for a rough pipe.

$$\lambda_{pipe,turb,rough} = \frac{1}{(2 \cdot log_{10} 3.71 \cdot \frac{d_{i,pipe}}{k_{pipe}})^2} \quad (9)$$

All other model components of the library are less complex. They are mainly implemented with reduced complexity, to contribute to a suitable simulation performance such as in the case of large grids with

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multiple house connection stations and complex pipelines.

The house connection station model is defined through an inverse model which calculates required volume flow dependent on simulated flow temperature and the associated return temperature (T_{Return}).

$$T_{Return} = \min(T_{Return,max}, T_{Flow} - \frac{Q_{Heat\ Consumption}}{c_{p,med} \cdot \rho_{med} \cdot q_{v,max}}) \quad (10)$$

The maximum return temperature ($T_{Return,max}$) is a system specific parameter, which depends on heating surface configurations and even more importantly, on hot water supply system type. Additionally, the return temperature is determined by the maximum volume flow of the considered house connection station. If the total heat consumption exceeds the defined maximum level, the maximum volume limit further decreases resultant return temperature.

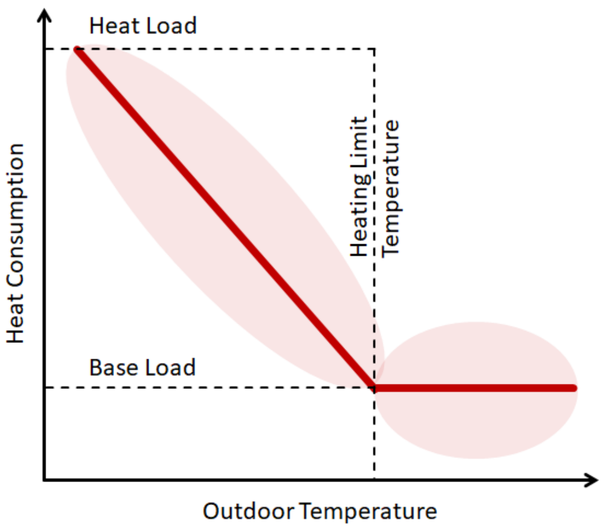

Figure 1: Concept of the heat consumption calculation in the House Connection Station model

The dynamic volume flow is only influenced by the temperature difference between flow and resultant return temperature as well as simulated heat consumption. To provide suitable simulation performance, the heat consumption is not calculated with a complex multi-zone building model but by a look-up representation of overall heat consumption of a building, dependent on outdoor temperatures (c.f. Figure 1).

This approach is especially feasible for residential or office buildings and building complexes as well as similar occupancy types. These building types do not include high internal heat loads nor major solar heat gains (if the window share is not higher than roughly 25%). Below the heating limit, the heat consumption is thus, mainly linearly dependent on the outdoor temperature. Above this limit, heat consumption is comparatively constant (i.e. base load) and is mainly influenced by occupancy specific heat consumption (i.e. hot water consumption).

The developed modelling approach describes the grid behavior in an inverse direction. It highly simplifies the simulation of individual buildings' thermal behavior by only using 10 parameters. The main results of a grid simulation include pressure and temperature behavior in different grid parts as well as the total required heat supply and pressure drop in the considered heating plant. This heating plant model provides an outdoor temperature dependent flow temperature (i.e. heating curve) as well as the maintenance return pressure. Further possible calculations include the total heat supply dependent on temperature difference, volume flow and total pressure drop dependent on resultant flow pressure. These values represent the most important dimensioning variables of a heating plant.

A district heating network can be constructed as a radial, ring or mesh system. Radial networks represent the simplest form of a network in which a large main pipeline feeds several distribution pipelines, forming individual branches. In these branches, the pressure of the main pipe is distributed homogeneously over all distribution pipes. The resultant flow pressure is again inversely calculated by the maximum pressure drop of all distribution pipes. The flow temperature for all branches corresponds to the main pipe and the return temperature is calculated using the mixing ratio of the distribution pipes.

$$p_{return,main} = p_{return,branch1} = p_{return,branch2} \quad (11)$$

$$p_{flow,main} = \max(p_{flow,branch1}, p_{flow,branch2}) \quad (12)$$

$$T_{flow,main} = T_{flow,branch1} = T_{flow,branch2} \quad (13)$$

$$T_{return,main} = \frac{q_{v,branch1} \cdot T_{return,branch1} + q_{v,branch2} \cdot T_{return,branch2}}{q_{v,branch1} + q_{v,branch2}} \quad (14)$$

Modelling ring or mesh systems requires additional components (i.e. pipe junction) which calculate the volume flow distribution between two pipes of a junction, depending on the pressure drop (c.f. equation 15).

$$q_{v,junction1} = q_{v,main} \cdot \frac{\Delta p_{junction2}}{(\Delta p_{junction1} + \Delta p_{junction2})^2} \quad (15)$$

A grid node is also added which is used to identify a specific point of the grid between two parts of one pipe (e.g. in case of a diameter reduction).

Furthermore, district heating grids can include two or more heating plants at different grid positions. This case highly increases the model complexity as it is not possible to implement such a structure with a complete inverse modelling approach.

Figure 2: Example grid structure and corresponding Modelica simulaton model as well as sample result representation

The main challenge in these models is to identify the dynamic movement of the grid point at which volume flow reversal takes place, especially if both heating plants work with different operation strategies (e.g. basic heat supply, residual heat supply).

The first approach to solving this modelling problem considered the application of the Navier-Stokes equation for the development of a non-inverse pipe model.

However, first implementations with this methodology showed significant disadvantages regarding simulation performance. The alternative approach implements pipe components (i.e. flow and return) with two inverse directions. The model is able to dynamically detect reverse flow and switch grid calculation between both pipe elements. This shows that to achieve maximum simulation performance more complex modelling techniques and methods are necessary. However, this disadvantage can be compensated using script-based partly automated modelling frameworks.

3 Modelling Framework

The library components described above show the implemented approach for modelling the behavior of a district heating grid in the Modelica modelling language. However, in this area of application, the main challenges faced are the parameterization of the model and the evaluation and presentation of the results. A typical district heating grid with a total length of approx. 50 km and 250 house connection stations requires the processing of 12,000 plus parameters as well as the evaluation of more than 1,000 grid components.

Most parameters of district heating grids today are already available in electronic form such as in data bases of GIS-based but static district heating grid simulation models (e.g. BENTLEY, STANET, etc.). These data bases can most often be easily exported to common data formats like *.csv or *.txt and therefore be imported in MS Excel.

Furthermore, SimulationX, the Modelica simulation environment used to implement the above described library components, provides a script-based (via Python or VBA) access to the simulation model via the MS COM interface. Imported grid parameters can thus be used to automatically parameterize the implemented district heating-grids, simulation model. Even the model structure itself (i.e. components' position, orientation and connections) can be implemented via script using model internal annotations. Therefore, the model structure represents real-world grid layout and available GIS data (i.e. x and y coordinates) provide sufficient information for automatic modelling.

Besides automated variant analyzes, SimulationX furthermore enables an automatic export of simulation results via the same COM interface (Neidhold et.al. 2018). Therefore, a set of suitable MS Excel templates and evaluation scripts provide an easy to use framework to integrate Modelica simulation models as well as common MS Office tools in a consistent workflow for district heating grid analyzes.

4 Simulation Examples

One complex simulation example is a medium-size district heating grid in a town in eastern Germany. It has a total pipeline length of approximately 50 km. The total installed heating power output is 20 MW which is divided by about 40% to 60% between a base load and residual load heating plant (c.f. Figure 2).

The grid only has to overcome slight geodetic differences in height of about 40 m. A maintenance pressure of an estimated 5 bar is thus provided by the residual heating plant.

The grid is currently under reconstruction. It previously consisted of two main individual grids, each with their own heating plant, supplying heat to the north western and south eastern part of the city. Both former grids will now be connected to one complex district heating grid with a base and a residual load heating plant. Furthermore, a small local heating grid in a peripheral residential area will be connected to benefit from the increased heat supply efficiency of the new grid with modern cogeneration power plants.

Finally, new customers of the district heating grid shall be acquired. Therefore, additional pipelines to peripheral buildings (e.g. a large school complex) will be built in the south west and north east area.

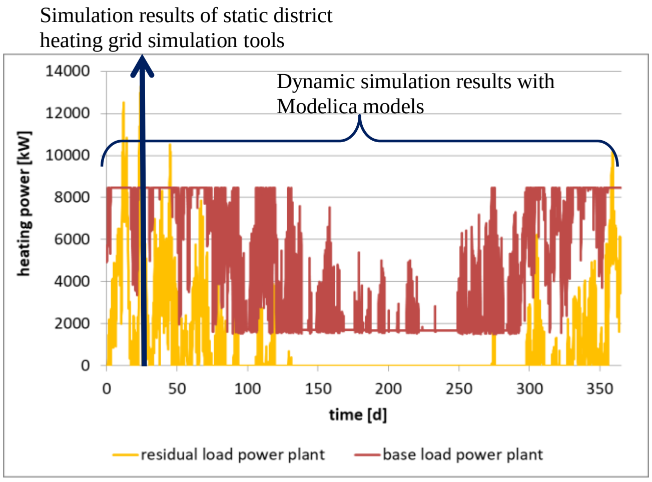

Figure 3: Simulated heat power output in both heating power plants in a reference year – Differences between static and dynamic grid simulation

To effectively plan the reconstruction it is necessary to analyze the resultant requirements on total heat supply as well as pressure drops in both heating plants with regards to the developed operation strategy. Additionally, an evaluation of all relevant grid areas in regards to maximum flow pressure as well as heat and

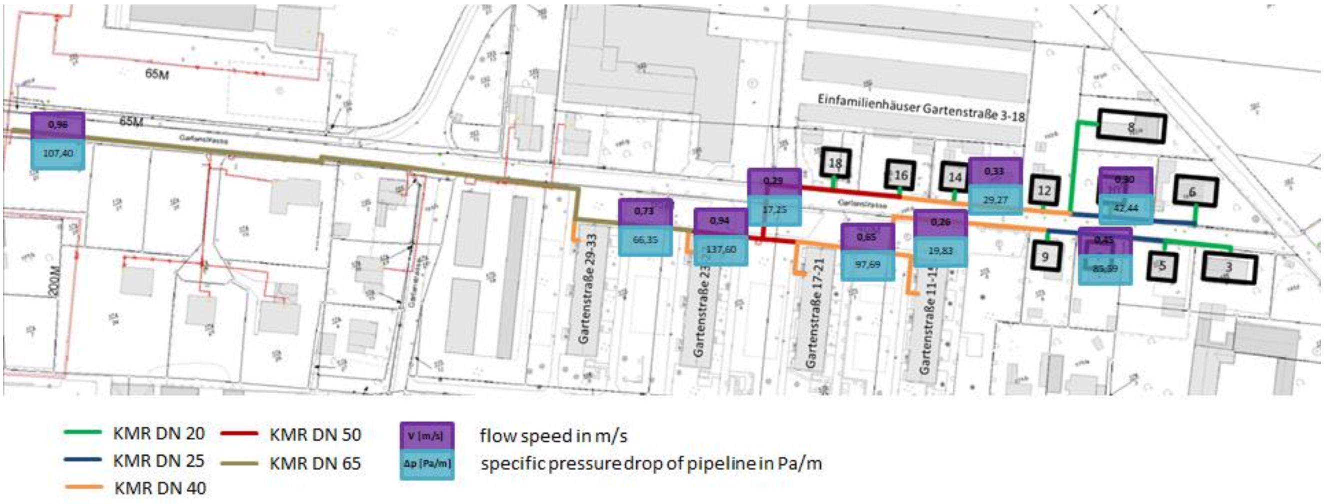

Figure 4: Example simulation results – maximum flow speed and specific pressure drop in one of the grid parts

pressure losses in varying pipelines, is necessary. This is ultimately required to confirm that the planned grid operation with the two power plants fits the requirements of all customers and all weather conditions. Furthermore, the simulation results are used in the sizing process to determine the right dimension of circulation pumps, cogeneration units as well as peak-power boilers.

Additionally, the simulation results characterize the remaining grid capacity of all grid parts which can be utilized (i.e. provide access to additional customers). They also indicate pros and cons of different piping solutions for additional grid parts.

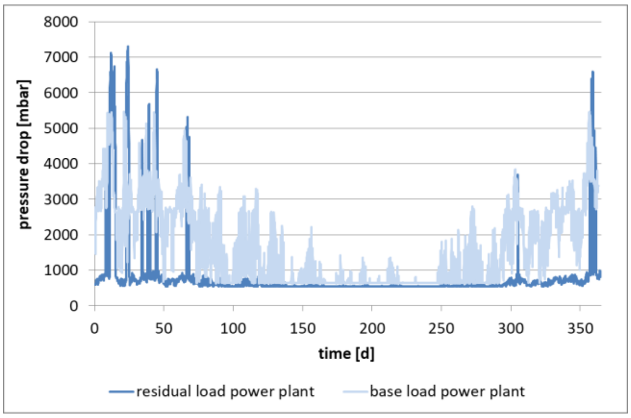

Figure 5: Simulated pressure drop in both heating power plants in a reference year

Figure 3 depicts one of the previously described result sets from the district heating grid simulation model, showing the dynamic heat power output of both the base load and the residual load power plant. It illustrates that most heat over the year is provided by the base load power plant (heat power output with a maximum of 9MW can be supplied for almost half of the year). The peak-power output of the residual heat power plant however, exceeds the maximum of the base load with about 13 MW at the end of January. This significant difference between peak load and base load (about 2 MW) results mainly from the connected residential buildings which only consume little amounts of heat to produce domestic hot water, during the summer time (base-load periods).

Figure 5 shows the corresponding dynamic pressure drop behavior in both heating power plants mainly dependent of outdoor-temperature specific, heat-power output. In times of shutdown the pressure drop at the residual power plant remains at the minimum level which is provided from the base load power plant at its grid position. During these times, the complete flow is provided by the circulation pumps of the base load power plant. In the case that peak-heat power is required, the pressure drop in the residual load power plant significantly increases (up to 7 bar), often even above the base load heat power plant pressure parameters (max. about 5.5 bar). In this case, most of the grid's customers are supplied by the residual load power plant.

Figure 4 furthermore shows a section of the grid in the north eastern area which shall be extended with additional pipes to supply further single-family houses. The main question regarding the maximum grid capacity in this area, that is posed, is if all considered buildings can be additionally connected to the grid without exceeding maximum capacity.

The simulation results showed that the maximum specific pressure drop in the considered pipelines as well as the maximum flow speed does not overrun pipe-specific limits (i.e. 1 m/s flow speed and 150 Pa/m specific pressure drop). Thus the model could confirm that the existing grid capacity is sufficient, to additionally connect all remaining single-family homes in the considered street.

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5 Heating Power Plant Models

The above described approach and methods enable the dynamic simulation of district heating grids which allows engineers to better evaluate and plan such grids. This results in more detailed and accurate grid parametrizations and information.

Using this information gain and utilizing the Modelica modelling language further aspects of district heating can be examined and developed. One of these areas is the development of detailed heating power plant models to test and evaluate unit commitment algorithms and methods.

Due to the global goal of decarbonization cogeneration units have been promoted as a middle-term solution to decentralizing energy production. These units combine power and heat production. This improves overall process efficiency and thus such units are common in district heating grids. The produced electricity is directly marketed on the stock exchange, meaning that prices vary on a quarterly hour bases (prices are released for the next 24 hours). Therefore, through utilizing heat storage capacities, the trade with production flexibility offers new economic incentives for heating power plant operators.

Operators are required to plan their power production for the next 24h (Day-Ahead Planning). To automate and optimize this planning process, unit commitment algorithms have been developed which take into account fluctuating electricity prices and future heat demands. These algorithms can mostly only be tested using simplified static verification methods. This can be problematic as simplifications are often made in the algorithm development process which cannot be tested or evaluated using these static methods. The following chapter will describe an approach that enables a dynamic simulation and evaluation of such algorithms using the Modelica-based library Green City.

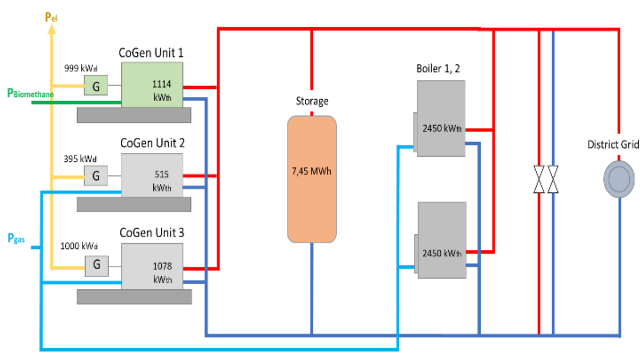

Figure 6: Example Heating Power Plant

Green City is a newly developed simulation library in ESI ITI's SimulationX for holistic modeling of heating, cooling and electric power supply, storage systems and consumption models in buildings and city quarters. It is based on the existing Green Building approach used to simulate sophisticated HVAC systems including renewables, storages, control strategy and eMobility.

To enable the above described dynamic simulation a model-based test platform was developed on the basis of an example heating power plant. The simplified example plant consists of 3 different cogeneration units, one heat storage system, 2 peak-heat boilers and a district grid (summarized as one thermal load).

The challenge of building the above example plant was that not all of the components needed where available in the standard Modelica libraries, like Green City in SimulationX. Since the cogeneration units needed to be controlled through external *.txt files (via a time-dependent reference power output curve) that were written by the unit commitment algorithms, an interface as well as a new unit controller was developed, that enabled the coupling of the planning algorithm and the model. Another Interface was established that enabled the link between the heat prediction algorithms (temperature dependent) and the district heating grid.

The cogeneration units were further developed to be able to adjust running cycles so that minimal unit modulations were upheld. Furthermore, the boilers control technology was adapted so that a peak-heat operating mode was possible. Utilizing these new library components a complete model based platform could be developed.

To examine the above developed model and test its validity different test scenarios were defined and implemented. The first looked at plausibility and the second at sensitivity to prediction errors. These test scenarios were simulated using three daily case examples which are defined through different heating periods (i.e. summer, winter, transition period). Furthermore 2 algorithm types were used to create different unit commitment plans for the above described example days. One algorithm applied only a heat-controlled operation (baseline algorithm) and the other implementing an electricity revenue optimization. This allowed for an overall validity evaluation of the described model and the investigation of the possibility of algorithm assessment.

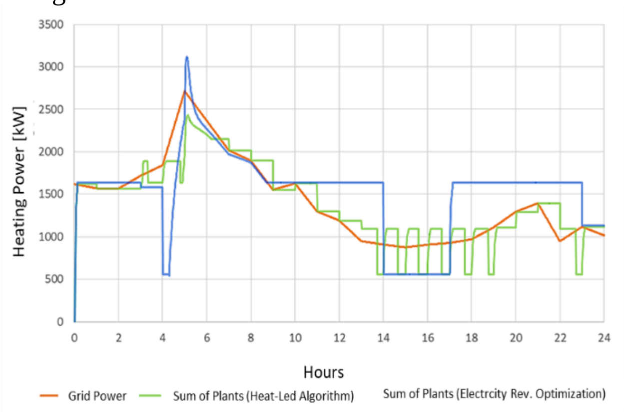

Figure 7: Example of Simulation Assessment

The following figure shows an example of such a plausibility investigation. It is visible that technological processes such as running cycle adjustment and peak power compensation through the boiler are correctly implemented within the model. Furthermore, the incorporation of the heating storage is visible in the flexible relocation of heat production.

The described test scenario evaluations showed that the Modelica based model was able to plausibly depict the system technology of a heating power plant including cogeneration units, taking into account physical and technological constraints. The developed simulation model thus, enables a dynamical and transient validation of unit commitment planning algorithms. The study shows that both the plausibility and sensitivity of such algorithms can be investigated using the developed model based test platform. This ultimately enables the optimization and evaluation of such algorithms before real world implementation. It also showed the advantages of dynamic investigations, using the Modelica modelling language, opposed to mere static approaches.

6 Conclusion

The presented simulation approach enables engineers and scientists to simulate thermal and hydraulic behavior of a district heating grid. Apposed to conventional GIS-based grid simulation tools, the developed approach using the versatile modelling language Modelica enables the consideration of weather dependent dynamic effects as well as storage capacity influences, over a year, within one model. This inevitably enables engineers to better evaluate part load conditions.

GIS-based grid simulation tools however, provide copious data bases of required system elements (e.g. pipes of different sizes and manufacturers) as well as an easy-to-understand frontend to illustrate simulation results with graphical references to individual grid parts on the map. To close this gap, the existing COM-Interface between the Modelica simulation environment SimulationX and MS Excel was extended to automatically build and parameterize gird models utilizing the imported grid data base. Furthermore, the interface was also used to implement post processing routines for result evaluation and graphic presentation.

The approach has been tested with sufficient measurement data of several example grids. The results are valid for district heating grids of small to medium size.

As an example, measurement data of another 20 km district heating grid in a small city in eastern Germany was used which allowed for a comparison of both thermal as well as hydraulic behavior of the implemented models. Figure 8 shows a brief comparison of the measured vs. the simulated pressure drop of this analyzed grid depending on the outdoor temperature. Due to the highly simplified approach of building modelling (c.f. Figure 1), the grid model cannot fully represent building storage capacities. This thus results in fluctuating measurement values regarding specific outdoor temperature. It however, sufficiently reproduces the hydraulic behavior in all grid parts (peak loads, basic loads) which are necessary for grid analyzes and system design.

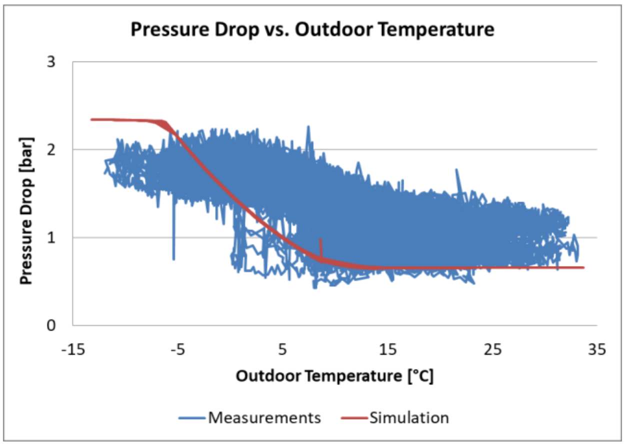

Figure 8: Comparison of measured vs. simulated pressure drop depending on outdoor temperature

The simplified modeling approach enables high performant models with sufficient simulation speed. A 50 km plus grid with about 2,000 grid elements and about 1,400 model states needs an estimated time of one to two hours for a yearly simulation. Furthermore, the dynamic modelling approach of Modelica enables the evaluation of 100+ grid operating points within a single simulation run. Existing static district heating grid simulation models only allow for the evaluation of one operating point with each simulation run (c.f. Figure 3).

Future development will include extended process automation to further expand the approach, enabling the simulation, evaluation and presentation of large-scale district heating and ultimately cooling grids.

Nomenclature

Following definitions and symbols are used within this paper to describe the model functionality in equations 1 to 15.

$\dot{Q}_{loss}$	- Heat loss over the insulation
$\Delta Q_{insulation}$	- Heat transmission coefficient of pipe
l_{pipe}	- Length of pipe
T_{med}	- Medium temperature
T_{ground}	- Ground temperature
Δp_{rough}	- Pressure drop of pipe dependent on pipe roughness
λ_{pipe}	- Pipe friction coefficient
ρ_{med}	- Medium density

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v_{pipe} - Pipe flow speed
$d_{i,pipe}$ - Inner pipe diameter
ζ_{pipe} - Pressure loss coefficient of pipe
Δp_{bends} - Pressure drop of pipe bends
$\Delta p_{fittings}$ - Pressure drop of pipe fittings
$\Delta p_{element}$ - Constant pressure drop of individual pipe fittings
Δp_{geo} - Pressure drop of pipe dependent on geodetic elevation differences
g - Gravity constant
Δz - Elevation difference
η_{med} - Dynamic viscosity coefficient
k_{pipe} - Roughness coefficient
Re - Reynolds number
$\lambda_{pipe,lam}$ - Pipe friction coefficient of laminar stream
$\lambda_{pipe,turb,smooth}$ - Pipe friction coefficient of turbulent stream for a smooth pipe
$\lambda_{pipe,turb,rough}$ - Pipe friction coefficient of turbulent stream for a rough pipe
T_{Return} - Return temperature
$T_{Return,max}$ - Maximum return temperature
T_{Flow} - Flow temperature
$Q_{Heat\ Consumption}$ - Building heat consumption
$q_{v,max}$ - Maximum volume flow of building's grid connection
$c_{p,med}$ - Specific heat capacity of medium
$p_{return,main}$ - Absolute pressure of main return pipe
$p_{return,branch1}$ - Absolute pressure of return branch1
$p_{return,branch2}$ - Absolute pressure of return branch2
$T_{flow,main}$ - Flow temperature in main pipe
$T_{flow,branch1}$ - Flow temperature in branch1
$T_{flow,branch2}$ - Flow temperature in branch2
$T_{return,main}$ - Return temperature in main pipe
$T_{return,branch1}$ - Return temperature in branch1
$T_{return,branch2}$ - Return temperature in branch2
$q_{v,branch1}$ - Volume flow in branch1
$q_{v,branch2}$ - Volume flow in branch2
$q_{v,junction1}$ - Volume flow in junction1
$q_{v,main}$ - Volume flow in main pipe
$\Delta p_{junction1}$ - Total pressure drop in junction1
$\Delta p_{junction2}$ - Total pressure drop in junction2

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