Holistic District Heating Grid Design with SimulationX / Green City

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Kurzfassung

Gebäude sind zentraler Bestanteil zukünftiger intelligenter Netze. Sie ermöglichen in diesen Netzen eine hinreichend genaue Vorhersagbarkeit der resultierenden Heiz- und Kühlbedarfe sowie die Ausnutzung zusätzlicher, vergleichbar großer Speicherkapazitäten in den jeweiligen Heizsystemen bzw. in der Warmwasserbereitung. Darüber hinaus stellt das Leistungsverhältnis zwischen Spitzen- und Grundlast für das Netz ein deutlich stabileres Verhalten dar als andere Systemkomponenten, wie z.B. Windkraft oder Elektromobilität.
In einer bayrischen Kleinstadt wird zurzeit ein Nahwärmenetz aufgebaut, welches teilweise mit solarer Wärme betrieben wird. Darüber hinaus liefern Wärmepumpen zusätzliche Speicherkapazitäten für Stromüberschüsse aus Windkraft im Netz des lokalen Energieversorgers. Kraft-Wärme-Kopplungsanlagen und Spitzenlastkessel ergänzen die Wärme- und Stromproduktion. Das Niedertemperatur-Nahwärmenetz versorgt dezentrale Wärmepumpen, die die Wärme auf einem deutlich höheren Temperaturniveau in den angeschlossenen Gebäuden bereitstellen. Dieser Beitrag beschreibt die Grundlagen der Nahwärmenetzsimulation mit SimulationX / Green City sowie Vorteile des neuen Ansatzes am Beispiel eines solargeführten Anwendungsbeispiels.

Abstract

Buildings are central elements of future smart grids. Heating and cooling demand are predictable within reason, building mass as well as heating and hot water systems provide inherent storage capacity. Additionally, the fluctuation between peak and average power of a building is much more friendly to the grid than of other network nodes like wind power or electric mobility.

A local heating grid partially supplied by renewable solar heat is currently built in a town in Bavaria. Heat pump systems provide additional storage capacity for electricity grid surplus while they serve as wind energy dump for the local utility company. Cogeneration plants and peak-power boilers provide heat and power in times of low energy coverage. The low temperature heating grid supplies decentral heat pumps, which provide required heat at a much higher temperature level to each building.
The paper describes basic modeling aspects for district heating grids with on SimulationX / Green City. An interesting solar-aided grid example helps to identify benefits of new modeling approach.

Introduction

Architects and HVAC system engineers more and more focus on building physics simulation and simulation-tool-based HVAC system design. This way, they can assure to find an optimal solution regarding various design decisions to be made. Renewable energy use as well as maximum lowered building heat consumption cause more complex system designs and comparatively higher user dependencies. Latest simulation tools, like Modelica-based Green Building in SimulationX, use probability-based approaches and a highly diversified model structure, e.g. including different types of heat and power storages as well as eMobility, to therefore give the engineers a suitable simulation environment.
However, future heating, cooling and power supply for buildings will not only focus on single buildings or building complexes. Engineers more and more focus on holistic grid design with a significantly higher number of buildings and different usage scenarios. This way, local synergy effects, like combined heat, cold and power production as well as waste heat use, benefit optimal system design. However, current simulation approaches are not fully-applicable regarding such large-scale simulation problems with a high number of sophisticated simulation models, input data sets as well as a comparatively long simulation time period.
This way, EA Systems and ESI ITI designed the new Green City simulation package in SimulationX which is mainly based on the already existing Green Building solution. The library focus on city-district-wide [2] coupled building structures including local district heating and cooling grids as well as local power production plants including large-scale renewables and storages as well as cogeneration. Like Green Building, this simulation environment uses easy-to-handle model components with a reduced set of system parameters to enable system engineers to make fast and viable design-decisions.

Green City Simulation Package

Green City is a newly developed simulation package in ESI ITI's SimulationX for holistic modeling of heating, cooling and power supply, storage and consumption in city quarter size. It is mainly based on already existing Green Building package which enables the user to simulate sophisticated HVAC systems including renewables, storages, control strategy and eMobility.

To cope the new challenges of system engineers as well as local utility companies Green City derives this widely-used approach of HVAC and power system modeling to large-scale problems. Basic model components design remains the same because most considerable boundary conditions are equal.

Power, heating and cooling supply in buildings uses solar or wind energy, any kind of fuel or even superior supply grids for energy production. The building directly consumes that energy or internally distributes it between or stores it in different forms of thermal, medium or electric storage. Large-scale grids mainly show similar behavior.

For example, combined heat and power units simultaneously produce heat and power in buildings. Cogeneration plants in large-scale heating and power grids play the same role. PV modules on top of a building have the same properties like large-scale photovoltaic power plants and wind parks always consist of specific wind turbine number. Power and heat supply systems basically provide size-independent functionality. Relevant differences exist regarding components size (e.g. hub height of wind turbines), influences of scalability (e.g. wake effect in wind parks) as well as interfaces (e.g. single/three phase grid connection in buildings vs. low/medium/high voltage connection in local grids).

Storages in buildings mainly use the same physical behavior like large-scale grid storage, e.g. hot water tanks compared to large-scale stratified heat storages, battery size between 2 kWh and 2 MWh only differ in the number and kind of battery cells.

Furthermore, overall energy efficiency highly depends on transmission losses between energy supply and consumption. Regarding heating, cooling and power supply, this mainly refers to heat losses through pipe insulation as well as voltage drops in cables. Both physical effects are easily-scalable.

Additionally, Green City adds new functionality regarding electric modeling. There are three more grid types (i.e. AC medium and high voltage, DC) with variable voltage levels. Like heat exchangers between different heating media or grid temperature levels, additional transformers as well as DC/DC converters help to convert one voltage level to another including suitable assumptions regarding transfer losses.

Green City's major added value are simplified statistic building models representing local heating, cooling and power consumption in different building types or even whole streets. These models automatically define hundreds of building physics parameters (e.g. wall thickness or insulation) via model-internal statistic data sets.

Low Temperature District Heating Grid

The presented sample project is a role-model for Green City use as a part of large-scale heat and power supply system design. The considered district heating grid provides heat to 100+ single-family-homes and dwelling houses with highest energetic standard. To reduce grid's heat loss share to a minimum with respect to overall system costs, grid temperature is lowered to a minimum level of 25 °C during summer. Modern combined heat pump systems including compressor and simple grid heat exchanger provide heat demand for domestic water supply in each connected building even at this low grid temperature level with a minimum of electricity consumption surplus.

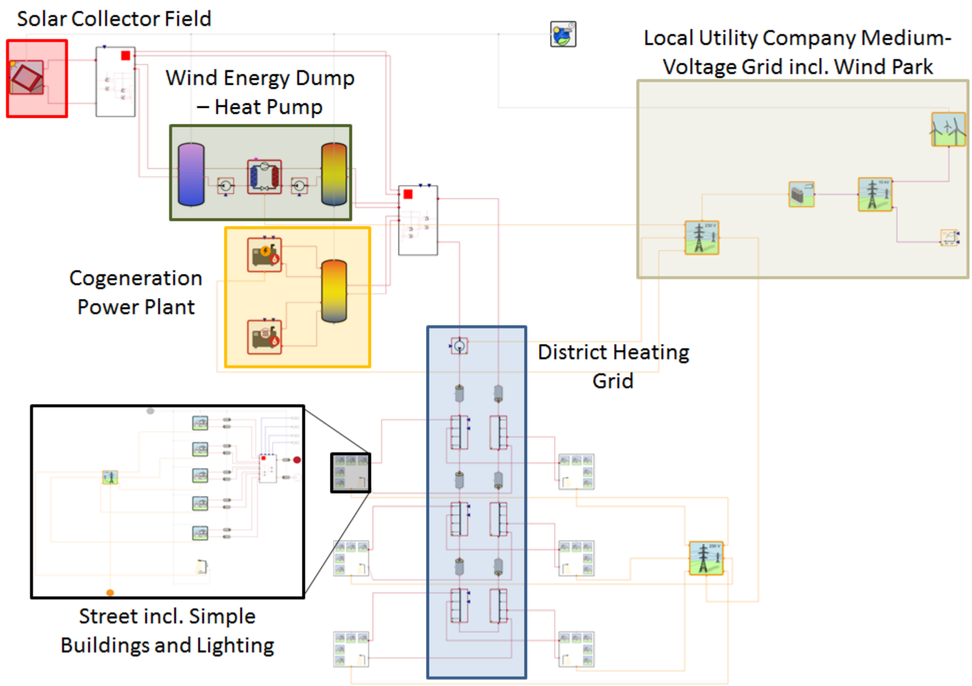

Figure 1: District heating grid model including solar collector field, virtual heat storage (wind energy dump), cogeneration power plant, local utility company grid and connected streets in SimulationX

Main heat is produced by a cogeneration plant which is supported by a large-scale solar thermal plant mainly during transient times and summer. To further increase solar thermal efficiency, a hydraulically decoupled heat pump system with two large-scale storages is installed. Because of existing storage capacities, local utility company can perfectly use this grid to provide negative and positive balancing power to avoid penalties. In times of renewable power surplus, heat pumps store freely available electrical energy as heat in the grid. Otherwise, cogeneration plant is used to simultaneously provide heat and power.

Sample Simulation Results

Main goal of system simulation is to find an optimal components configuration with an optimal control strategy. This multi-criteria optimization problem [1] requires a comparatively huge number of simulations in a preferably short time period. This way, Green City higher prioritizes fast and easy modeling and simulation than detailed model and parameter set accuracy.
Figure 1 shows implemented model of the partly renewable district heating grid example in SimulationX. Engineers with it identified deficiencies and optimization potentials of initial system concept (e.g. influences of non-insulated cold return pipe, operation time of heat pumps) analyzing a number of different components configurations and control strategies.

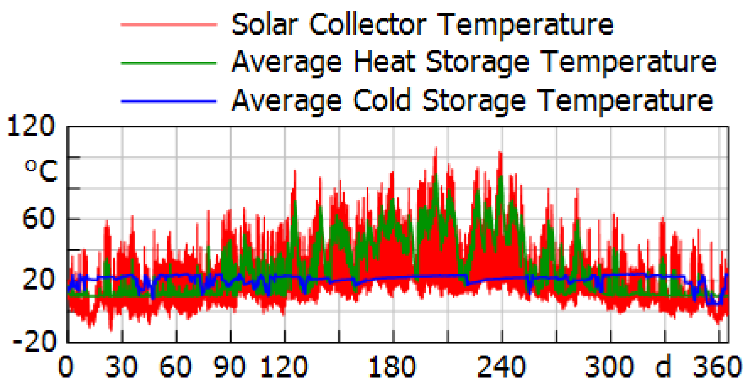

Figure 2: Solar collector, heat and cold storage temperature behavior

Figure 2 shows simulated temperature behavior for a solar thermal collector size of 800 m^2 as well as heat and cold storage size of 50 m^3 each. District heating grid directly consumes solar heat gains most of the year. However, these heat gains partly exceed overall heat demand even with a comparatively large-scale storage during summer (i.e. heat storage temperature often exceeds 60°C level while only 25°C is required). The heat pump can only use little solar gains as heat source with a lower temperature level in the cold storage during winter times. This way, heat pump's annual operation time is quite low (lower than 500 h a year for a 30 kW heat pump). Number and size of system components has to be reduced due to profitability requirements.

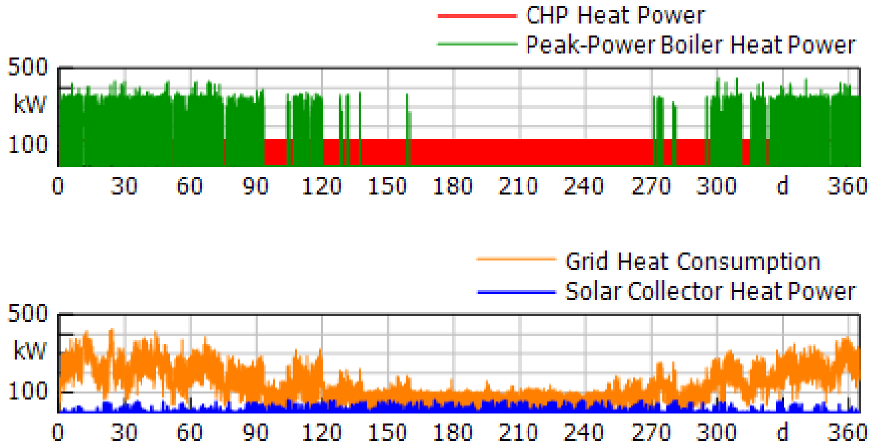

Figure 3: Heat production and consumption of solar aided district heating grid

Figure 3 shows some other simulation results of an adapted system configuration. This system only includes a reduced 100 m^2 solar thermal collector and only a 30 m^3 solar heat storage without any additional heat pump. This way, solar collector gains are able to buffer almost all grid heat losses during transient time and summer. The CHP runs 6000+ operating hours a year and peak-power boiler operation is minimized.

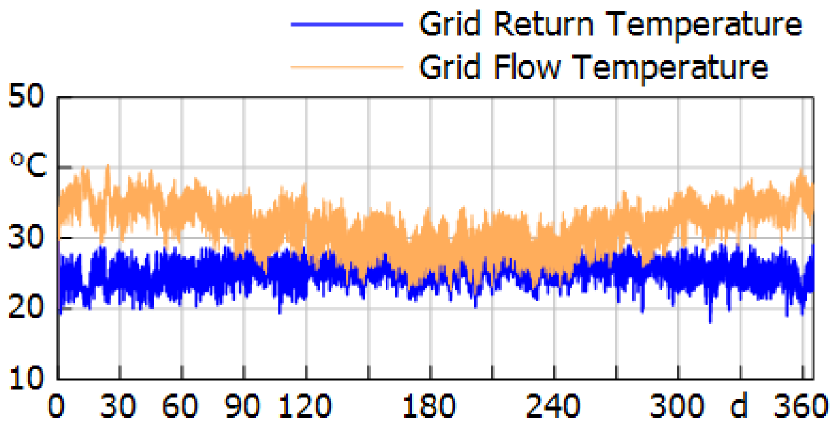

Figure 4: Simulated grid flow and return temperature

The adapted system configuration fits quite better to given heating system requirements. Figure 4 therefore shows overall grid flow and return temperature. This behavior mainly refers to basic strategy to lower grid flow temperatures during summer times. Return temperature remains at the same low temperature level during the whole year. This miminizes grid heat losses.

Summary

This paper describes the new simulation package Green City in ESI ITI's SimulationX and concerning this matter one interesting application example of a solar aided district heating grid.

Green City provides easy-to-use models to implement fast and accurately running models of huge building complexes or city quarters as well as large-scale renewable heating, cooling, power supply and storage systems.

The presented district heating grid example presents some of the benefits of the new simulation package regarding the upcoming challenges of building designers and local utility companies.

References

[1] T. Schwan, R. Unger, C. Lerche, B. Bäker. Multi-Criteria HVAC Systems Optimization with Modelica. 14th Conference of International Building Performance Simulation Association, Hyderabad, 2015.

[2] T. Schwan, R. Unger, C. Lerche, C. Kehrer: Model-Based Design of Integrative Energy Concepts for Building Quarters using Modelica. 10th International Modelica Conference, Lund, 2014.