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Modelling for Multi-objective Optimization in a District Heating Network

Abstract: Aim of the research is to develop tools and solutions for the multi-objective optimization of energy systems to be adapted in the prevailing conditions. One aim is to provide scalable integration procedures for solar thermal and exhaust air heat pump systems. Another aim is to develop online data quality monitoring. Third aim was to predict the future states of the heat pump with the measured data. Main research task was to develop multi-objective optimization. The research was done in co-operation with several companies and different research institutes. Research reported in this article is done in University of Oulu.

Keywords: optimization, district heating, multi-objective

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1 Introduction and background

Increasingly complex energy systems require new tools to perform it efficiently. In addition to increasing complexity, the uncertainty in the energy production and consumption increases due to increasing amount of intermittent renewable energy generation and more involvement in the demand side. The increasing amounts of data available from energy systems can help to improve the performance of energy systems, but the collection, transmission and processing of the data is challenging.

Multi-objective optimization is becoming important in balancing environmental impacts together with the economic costs and operation of the energy system. Furthermore, many of the published articles on multi-objective optimization in energy systems are related to the optimization of the design of the energy systems and not on the operational optimization.

Optimization solutions need to be modular and use advanced predictions on energy production and consumption. These predictions will utilize advanced weather forecasts that include uncertainty. Integration of heat and electricity is expected to reveal new synergies in the energy system. With this approach better management of energy systems can be achieved increasing the overall energy efficiency of the systems.

There are high flexibility potentials through storages and demand responses when integrating with the district heating. Interfaces are needed with the system level optimization to exchange information on situations, capacities and allocation.

2 Aim

Aim of the research is to develop tools and solutions for the multi-objective optimization of energy systems to be adapted in the prevailing conditions. Use of advanced weather forecasts aims to improve predictions on the state of energy devices and enable the inclusion of the uncertainty in the optimization. The integration of heat and electricity including production, distribution and demand aims to more efficient energy systems.

Modular optimization solution facilitates the applicability of the approach to different systems. Furthermore, the project provides environment for new business models. The solutions introduce new business opportunities in the energy production as well as in the case studies.

3 Research, case studies

The energy systems are undergoing a transformation from a centralized fossil- fuel oriented supply chain into a decentralized energy system with renewable energy. Decentralization of the energy system is causing an increase in complexity, which is why proper energy device integration is important to ensure good performance in the whole system. Research aims at providing scalable integration procedures for solar thermal and exhaust air heat pump systems. Synergy between district heating networks and the power system is also considered in exhaust air heat pump integration. [1]

Data quality monitoring is an important aspect in real-time data-based operation and of growing interest. Studying the different methods and approaches in real-time data quality monitoring, in the context of the energy systems, can yield some highly beneficial improvements in the ever-growing demand for material efficiency and energy savings. Quality flags, based on appropriate quality dimensions, can improve the decision making of systems in real time. The goal of this study is to find out, how this can be applied, utilizing the varied and large volumes of energy industry data. [2]

One aspect was to predict the future states of the heat pump with the measured data. The aim was to find answers to question that what kind of data-based methods can be used to effectively predict the operation of heat pumps and how changes in the state of these systems can be detected. [3]

Optimization simulator was developed to study multi-objective optimization in district heating systems. The optimization considers economic and environmental objectives and includes production-side as well as demand-side. Different production and storage technologies can be considered including combined heat and power (CHP) plants, heat-only boilers (HOB), heat pumps, solar panels, solar thermal collectors and heat and electricity storage. Demand-side includes the flexibility of the buildings in form of thermal storage capacity and own production like heat pumps, solar panels and solar thermal collectors.

CHP and HOB plants are modelled considering the thermal and electrical efficiencies and ramp rates. Heat pumps can be air-source, ground-source or water-source heat pumps. Their coefficient of performance (COP) is based on the temperature difference between the sink and source temperatures. Efficiencies are used to calculate the solar energy production. The efficiency of the solar thermal collectors is based on the temperature difference between the mean collector temperature and outdoor temperature and the solar irradiance. For storage systems, heat losses and discharge and charge efficiencies are considered.

Dynamic heat demand model is used to predict the heat demand for the buildings [4]. Considering the heat losses and time delay related to the district heating network, the heat supply is predicted based on the predicted heat demand [5]. Dynamic indoor temperature model is used to calculate the flexibility potential of the buildings utilizing their heat storage capacity [6]. Based on the predicted heat demand, heat supply, the flexibility potential of the buildings and their own production, the energy production and the utilization of storage is optimized considering both the economic and environmental aspects. The objectives can relate to both the production-side and demand-side. The optimization problem is formulated as a set of linear equality and inequality constraints and solved using mixed-integer linear programming (MILP). Novelty comes from multi-objective approach and the inclusion of demand-side flexibility in form of heat storage capacity of buildings and their own energy production.

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