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Spatial Distribution of Thermal Energy Storage Systems in Urban Areas Connected to District Heating for Grid Balancing

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Abstract

Fluctuating renewable energy sources and its rising share in the electricity grid need to be balanced. Thermal Energy Storages (TES) can buffer thermal energy generated by various energy converters, e.g. Combined Heat and Power Plants (CHP) and Heat Pumps (HP), for supplying a lack or demanding a surplus of electricity energy from the power grid. Simultaneously generated heat energy can be demanded from households in heating applications later. However, in dense populated areas, installation sites for thermal energy storage systems are rare due to a large building area. Hence, the spatial distribution of thermal energy storages can increase flexibility options for the operation of energy converters.
The installation and operation of thermal storage systems are analyzed with a mathematical optimization tool. Spatial distribution and utilization of certain energy converters are calculated on hourly base. The optimization is driven by a cost minimization related to invest, maintaining and fuel consumption. Simultaneously, the revenues for selling electricity at the electricity market are maximized. Technical and economical limitations are implemented in various scenarios in order to analyze the flexibility options with the spatial distribution and operation of thermal energy storages.

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*Keywords:*Grid balancing; flexibility options; spatial distribution; techno-economical optimization; structural and operational planning of energy supply system in residential area; Thermal Energy Storage (TES) system; District Heating Network (DHN); Combined Heat and Power (CHP) plant;

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1. Introduction

The rising share of fluctuating renewable energy sources requires extensive adaptions in the energy supply system of e.g. Germany. Not only the electricity sector but also the heat sector are concerned strongly [1]. Thermal Energy Storage (TES) systems in combination with Combined Heat and Power Plants (CHP) can balance energy demands in the electricity grid [2]. Electrical energy is generated by CHP plants in times of high spot prices at the European Energy Exchange (EEX) based on the simplified assumption that a lack of electricity energy in the power grid correlates to high prices at the electricity market [3]. Excess heat energy is buffered in thermal energy storage systems for later use in heat applications at buildings [4].

Thermal energy storage systems can increase the flexibility options for a decoupled generation and consumption of heat and electricity energy. Moreover, the operator of energy supply systems can increase its total revenues by the expansion and intelligent operation of thermal energy storage systems [5].

1.1. Objective

In practice, the space for installing large centralized thermal energy storage technologies is limited by large space requirements in dense covered areas. Hence, thermal energy storage systems can be distributed at open space in energy supply systems with district heating networks for increasing the options of a decoupled generation of heat and electricity energy.

In this paper, the flexibility options with decentralized thermal energy storage systems are identified. The ideal spatial distribution, the size and the operation of thermal energy storage systems are analyzed and compared to central TES systems in various scenarios by the means of a case study with a mathematical optimization tool.

1.2. State of the art

Increasing full load hours in CHP plants coupled to a long-term TES are shown in [6] with mathematical optimization algorithms. Varying hourly prices for electricity and fuel over fixed periods influence the payback time of the used technologies. Another study points out the optimal thermal energy storage capacities in the energy supply system of Berlin supplied by CHP plants and district heating networks [7]. Not only the operation but also the size of thermal energy storage systems are optimized with regard to high and low prices for fuel, electricity and CO2 emissions. According to the authors, including thermal energy storage systems can improve the efficiency of the whole energy supply system.

In the discussed energy optimizations the thermal energy storage is centralized and located nearby the CHP plant. In further research work mathematical tools are presented which allow the structural and operational optimization of spatially distributed energy systems with several thermal consumers at different locations: In [8], the optimal combinations of spatially distributed energy supply systems, thermal energy storages and consumers are calculated with a structural optimization algorithm. In comparison, in a further optimization tool [9] the spatially distributed energy systems and the connections to the district heating network have to be specified in advance. The great benefit of this tool lies in the hourly resolution of the optimization method, which allows the interpretation of energy generation and energy exchange.

2. Methodology

The techno-economical optimization tool “KomMod” allows the structural and operational optimization of distributed energy storage systems by an overall cost minimization of invest, maintenance and fuel consumption as well as the maximization of the revenues [10], based on an algebraic modeling language [11]. The optimization tool is used to analyze the spatial distribution of thermal energy storages and its operation is studied in the energy supply system of the neighboring residential districts Freiburg Weingarten and Freiburg Rieselfeld. Limitations in space for installing storage systems and heat transportation restrictions in the district heating pipes are analyzed in various scenarios.