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Influence of Spatially Varying Costs on Structure and Operation of Energy Storage and Supply Facilities in a Local Energy System

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Abstract

Thermal and Electrical Energy Storage (TES and EES) systems can balance the fluctuating energy supply of renewable energy sources for satisfying the energy demands. The extension of central TES systems is an appropriate measure for buffering surplus heat which can be produced by Combined Heat and Power Plants (CHP) or Heat Pumps (HP) for acting optimally on the electricity market. In addition, EES systems installed in combination with roof-top photovoltaic (PV) power plants can increase the self-consumption in buildings and reduce surplus electricity in the distribution grids. This research applies a spatially resolved techno-economical optimization method at a residential area for studying the future development of total costs, CO_2 emissions, energy exchange and stored amounts of energy for TES and EES systems in various scenarios. By the implementation of cost penalties in the model, the behavior of various operators for PV-battery systems is emulated. An increasing self-consumption and decreasing overall electricity exchange is stimulated by creating incentives for trading electricity within the studied local area.

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1. Introduction

Thermal and electrical energy storage systems (TES and EES) play key roles in energy supply systems which are increasingly dominated by renewable energy generation [1]. The fluctuation of renewable energy resources can be balanced by TES and EES systems for ensuring a continuous heat and power supply [2]. However, the transition of fossil fuel based energy supply systems towards renewables strongly depends on a smart interconnection of the energy sectors heat, electricity and transport [3].

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In cities, smart thermal networks are a highly sufficient option for an efficient heat supply and establishing a linkage to the electricity sector with various energy converter technologies [4]. Centrally located and fast reacting combined heat and power plants (CHP) can supply heat and electricity to households. The implementation of large central TES systems allows a flexible electricity generation of CHP units for increasing the revenues at the electricity market and balancing the fluctuation of renewables. Surplus heat can be buffered in central.

TES systems and supplied to consumers in times of low prices at the electricity market, whereby the additional use of conventional boiler units can be reduced [5]. Moreover, increasing renewable energy sources cause surplus electricity at the power grids which can be used by heat pumps for generating heat very efficiently for low-temperature systems at buildings [6], [7].

EES systems, especially Li-Ion batteries, are supposed to be one of the most promising options for stationary applications due to high technical performance and drastic cost reductions expected for the future [8]. Implementing batteries combined with roof-top PV-generators become a viable option for operators of photovoltaic power plants in the private sector. Considering the highest end-customer prices for electricity at private households, strong incentives for self-consuming electricity at PV-battery systems are created [9].

1.1. Objective

In this paper, scenarios for future potentials of central thermal energy storage (TES) systems and decentral located electrical energy storage (EES) systems are calculated by the means of a case study at a residential area. The ideal size and the operation of a central TES at a heating station and EES systems at roof-top PV-systems are determined with a techno-economical optimization tool on hourly base. By setting up different cost structures in the spatial model approach the boundary conditions for several operators of EES and TES systems can be emulated and studied in detail.

1.2. State of the Science

Holistic modeling approaches and analyses of urban energy supply systems based on case studies are presented in [10] and [11]. A method for optimizing the local distribution and operation of energy supply systems connected to district heating and cooling networks is presented in [12] and [13] at specified year intervals. In [14], optimal locations of energy supply systems are identified by comparing various scenarios. An approach for analyzing the distribution of central TES systems at district heating networks is introduced in [15].

The investment costs and the operation of PV-battery systems are calculated in [16] and the installation of batteries is supposed to be profitable in the range of 100 to 150 € per installed kWh_{el} capacity. The amount of self-consumed electricity and its increasing rate due to the installation of batteries is quantified in [17]. A techno-economical optimization approach at district level is presented in [18] whereby significant cost reductions for EES systems are expected by trading electricity between buildings.

2. Methodology

In the following, an example district in Freiburg, Germany, is presented by defining the thermal and electrical energy supply systems for the future. Furthermore, the optimization method, the modeling approach and the definition of scenarios for analyzing central TES and decentral EES systems including different operator modes are discussed.

2.1. Case Study: Example District in Freiburg, Germany

The research work of this paper is based on an example district which is located in Freiburg, Germany (Figure 1). In a preliminary study, three spatial zones were chosen for further analyses of its energy supply systems according to geographical cluster analysis [19]. High heat energy demands in the residential buildings of every zone lead to the assumption that the implementation of a district heating network with a central heating station and an expanded central TES system at open space is a prosperous option for supplying heating energy in the future. A refurbishment