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Optimal Use of Energy Storage Potentials in a Renewable Energy System with District Heating

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Abstract

Growing shares of intermittent renewable energy sources in power systems lead to temporal imbalances between electricity supply and demand. Technologies which help to balance the electric grid such as energy storages, demand response or flexible cogeneration concepts are therefore gaining on importance. However, the investigation of these potentials from a system perspective requires a simulation approach that takes into account the interactions between supply and demand side as well as power system stability. While most prior studies utilize either linear optimization models to investigate storage options on a system level, or nonlinear simulation models for power system analysis, the present work utilizes a combination of both approaches.

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Keywords: Grid balancing, Flexibility options, District heating network (DHN), Combined heat and power (CHP) plant, Power generation dispatch, Frequency Control, Renewable energy sources

1. Introduction

In order to reduce the emissions from electricity generation, Germany aims to cover 80 % of its gross electric energy consumption with renewable energies (RE) by the year 2050 [1]. However, the integration of wind and solar energy into the existing energy supply system has proven to be challenging due to the fluctuating nature of the specific energy offer. As a result, these fluctuating renewable energies (FRE) can not be used for load following or the provision of balancing reserve power in the same way as conventional generators.

Furthermore, the inverter connected FRE plants do not contribute to the electric grid inertia because their rotating masses, if present at all, are electrically decoupled from the grid frequency. This results in an electric grid inertia that is on average lower than in conventional systems and time variant, as it depends on the current FRE production [2].

This can lead to situations where the fluctuating energy offer from FRE must be curtailed because conventional power generation can not be reduced further without endangering the electric grid stability [3]. Similarly, cogeneration plants may be forced to produce electricity to cover the thermal demand in district heating networks. When

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investigating energy storages and demand response, in order to improve the FRE integration, electric grid stability issues as well as coupling effects between electricity and heat generation should be considered.

The TransiEnt.EE project investigates these effects in coupled energy systems, using an integrated simulation approach. For this purpose, the energy system of the city of Hamburg is being investigated as a reference case. Having a well developed district heating grid that covers approximately 20 % of the local heat demand, as well as a broad range of both, small residential and large industrial energy consumers, the considered system is complex enough to investigate coupling effects between energy transmission grids, but still manageable with respect to computational complexity.

1.1. State of the art

Prior studies, e.g. [3–6], utilize mixed-integer linear programing (MILP) to investigate the optimal use of storage technologies in power systems with high share of FRE. In these models, the minimum of a cost function is numerically approximated, while the solution must satisfy certain constraints. The solution vector contains, depending on the scope of the investigation, the operating state, power output and sometimes the capacity of the generation units.

[5] indicates that reducing the must-run generation induced by cogeneration plants can lead to a better integration of FRE. Furthermore, the study identifies demand response with heat pump systems as an effective measure to balance FRE offer and demand. Interactions between these flexibility options with electric power system stability are not investigated, however.

The influence of FRE on power system stability from a system perspective is investigated in two kinds of prior studies. The first, used by, e.g. [3,7] is the incorporation of stochastic analysis in linear optimization models. [3] compares different formulations of unit commitment models that minimizes a weighted sum of possible scenarios of the target function. While this approach leads to significantly higher computational cost as the deterministic unit commitment model, the study finds that conventional power reserve planning is overly conservative and therefore significant financial benefit can be gained by using stochastic optimization.

[7] follows a similar approach by incorporating the results from statistical analysis of wind power production and prediction data into a MILP model. The statistical analysis carried out shows that wind power can meet the technical requirements for balancing power provision with similar reliability levels as conventional generators. The study finds furthermore, that dynamic sizing and allocation of reserves lead to a reduction of system cost, since less power plants are needed and thus more wind energy can be integrated.

The second kind of studies uses system simulation with nonlinear models. Several authors [8–10] use a modeling framework based on a generic power node equation that is used for all components of a power system. The economic dispatch is simulated continuously using model predictive control with different prediction horizons to model day-ahead and intra-day markets. The focus of these studies lie in the investigation of power system operating strategies and the implementation of demand side management from a control theory point of view. [10] shows that secondary balancing reserves can lead to a must-run conventional generation and thus limit the use of fluctuating energies. He also states that heat-led cogeneration plants can secure the demand of secondary balancing power, but the interconnection between balancing reserves and integration of fluctuating energies is not quantified. [11] proposes a heuristic algorithm for the unit commitment problem and uses the results in a system simulation with dynamic models. The study evaluates the changes in control power demand in power systems with high share of wind energy. However, the provision of control power with alternating technologies is not part of the investigation.

1.2. Objective

The present work proposes a simulation approach that allows to simulate the interactions between the demand and supply side of power systems which are coupled to a district heating network. Different measures for the better integration of FRE can be analyzed with this method, while taking into account the power system dynamics and frequency control. Using a case study, the provision of balancing power by FRE generators, load shifting using heat pump systems and the electricity-led operation of cogeneration units in a power system with high share of FRE is investigated.