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Control power provision with power-to-heat plants in systems with high shares of renewable energy sources – An illustrative analysis for Germany based on the use of electric boilers in district heating grids☆

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ABSTRACT

Control power for the reliability of electricity supply is currently mainly provided by conventional power plants. In the situation of low residual power demand, the provision of negative control power may lead to must-run generation through base load power plants. Due to low wholesale electricity prices during low residual power demand, the must-run power plants that provide control power are confronted with high opportunity costs. Alternatively to base load power plants, electric boilers in district heating grids could provide relatively cheap negative secondary control power. The effects of the availability of electric boilers in the German control power market on overall system-wide costs and CO_2-emissions of the power supply are assessed using a model-based analysis for 2012 and 2025. Power-to-heat plants are able to dissolve the conflict of must-run generation of base load power plants for control power provision. Therefore, they can enhance the integration of fluctuating RES (renewable energy sources), which in turn can reduce overall CO_2-emissions of the power supply. The growing share of RES in Germany as well as cost reductions of electric boilers that can be expected in the next years could lead to a situation where the overall cost savings exceed the necessary investment costs.

1. Introduction

1.1. Motivation

In power systems a balance between generation and consumption has to be maintained at any point in time. For this purpose generators or consumers offer control power to the system which can be called off in the case of a system imbalance. In Germany, control power is currently mainly provided by thermal power plants [1], which provide both positive (capability to increase generation) and negative reserve capacity (capability to reduce generation). In particular, the provision of negative control power leads to a significant so-called *must-run generation*, which remains as a solid base on the supply side of the electricity market due to the technically required minimum output of thermal power plants. Fig. 1 illustrates the related limitations of thermal power plants originating from the provision of reserve capacity on the operation. Thermal power plants are only able to vary their generation between the maximum (P^{max}) and, in order to secure a stable operation, a certain minimum (P^{min}, e.g. 40%) output. When assuming a power plant with maximum output of 500 MW and 40% minimum output (200 MW), 50 MW of negative reserve capacity would require a generation of at least 250 MW as must-run generation. In that case, the fivefold generation therefore would be necessary for providing 50 MW of negative reserve capacity.

Fig. 2 illustrates the opportunity costs C^{opp} of negative control power from different technologies. Plants that are "in the money" (i.e. those which were selected to deliver power on the spot market) have zero opportunity costs as their variable costs are below the spot market price. Power plants that are out of the money incur positive opportunity costs depending on their variable costs (the lower the variable costs are, the lower are the opportunity costs) [2]. According to [2] this means if the variable costs are c^{var} and the spot market price is P_{Spot} than the opportunity costs for negative reserve capacity RC_{neg} are

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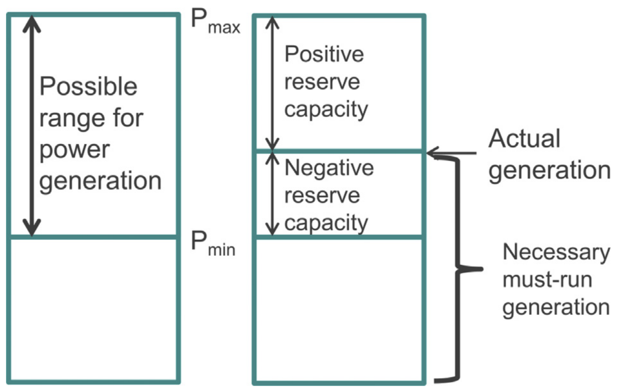

Fig. 1. Illustration of limitations for reserve capacity provision due to minimum and maximum generation of thermal power plants.

$$C^{opp} = \begin{cases} 0, & P_{Spot} \geq c^{var} \\ \left(c^{var} - P_{Spot}\right) \cdot \left(P^{min} + RC_{neg}\right) \Big/ RC_{neg}, & P_{Spot} < c^{var} \end{cases}.$$

In addition, because the bidding period for secondary control power in Germany currently is one week, the plants offering in this market need to maintain their capacity for the entire period. Plants delivering power from fluctuating RES (renewable energy sources, e.g. wind turbines) are not capable to provide secondary control power as the prediction accuracy for the time frame of one week is not sufficient.[1] With this situation the question arises, whether today the usage of thermal power plants for reserve capacity causes unnecessary additional CO_2-emissions in the case of a low residual[2] power demand. Furthermore, in times with low residual load, the wholesale electricity prices on the spot market become negative [4]. In some cases, there are even high negative prices up to - 500 EUR/MWh. End users of power will have to pay the resulting high opportunity costs of the power plants which provide reserve capacity in these times through their grid fees.

Although the expansion of RES in Germany in the last years has not yet led to an increase of the control power demand (due to improvements in the cooperation of the German transmission system operators, see Ref. [2]), many studies project a rising control power demand in systems with high share of fluctuating RES [3,5]. The desired progressive expansion of electricity generation based on weather-dependent power producers (wind power, solar photovoltaic) in Germany may lead to even more conflicts with the must-run power generation in conventional power plants, which have to stay online for the provision of system services even in hours of low residual demand.

Alternative providers of negative secondary control power are electric boilers[3] (power-to-heat plants) that are integrated in district heating grids. The use of electric boilers in district heating grids offers several advantages. With 88–180 EUR/kW the

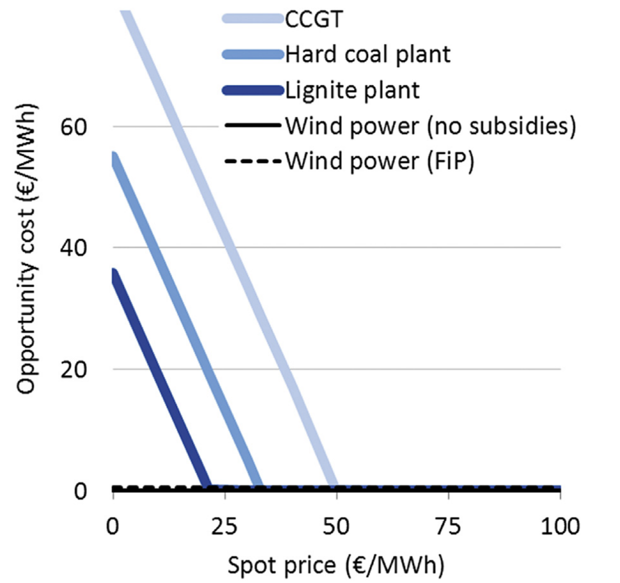

Fig. 2. Overview of opportunity costs of providing negative control power (CCGT = combined cycle gas turbine; FiP = Feed-in premium). Source: [2].

construction costs of the plants are relatively low [6]. The integration of the power and heat sector would enable the use of the existing and expandable heat storage potential of the heating grids which could be immediately used for excess electricity from the power grid. Overall, the technical power-to-heat potential in the large district heating grids alone in the control area operated by the 50 Hz Transmission GmbH in Germany amounts to 5.6 GW_{el} [7]. Taking this potential into account, the present analysis investigates the impact on the cost and CO_2-emissions from power generation, should 1000 MW in the form of electric boilers in district heating grids be available in the market for negative secondary control power. The corresponding analysis is performed for the year 2012 and after the nuclear phase-out in Germany (2025).

1.2. Related literature

The topic of must-run generation of power plants in Germany due to the provision of system services was discussed e.g. in Ref. [8]. For the ability to balance generation and consumption at any time, they calculated a must-run generation of 8–25 GW. Ritter [9] analyzes to what extent the reduction of the must-run generation from 20 to 5 GW reduces the curtailment in Germany in 2020, 2030 and 2050. Schill [10] investigates the necessary amount of electricity storage capacity in Germany (for 2022, 2032 and 2050) under the assumption of a must-run generation of 20, 10 or 0 GW in the market at any time. He finds that the lower the must-run generation and therefore the more flexible the German power system is, the less curtailment of RES is necessary and the less power storage will be needed. Both before-mentioned sources define the must-run generation ex-ante and not depending on the different situations in different times of the year. In this paper the must-run generation will be endogenously determined depending on the ex-ante defined reserve capacity demand. Furthermore, Totschnig et al. [11] investigate the Austrian and German power system for a 2050 scenario and find that the power-to-heat application supports the integration of RES. Furthermore, Schaber et al. [12] analyze a 2020 and a 2050 scenario for Germany with a model that couples different energy sectors. Their results show that heat generation from electricity can make up to 40% of the heat demand

[1] There is an ongoing research about the ability of renewable energy sources of control power provision (compare e.g. Ref. [3]). The regulatory framework should also be adapted in the future to facilitate the participation of renewable energy plants at the control power market.

[2] The residual load equals actual demand for power minus supply from RES.

[3] The authors focus on electric boilers for heat provision in the context of district heating and do not consider heat pumps or night storage heaters. As the call-off frequency in the control power market is comparably low, technologies with low investment costs (but a possibly worse efficiency) might be more economical. In this context electric boiler are considered to be more advantageous compared to heat pumps due to their investment cost advantage. The usefulness of electric boilers in comparison with heat pumps for different marketing strategies (spot and/or control power market) should be further investigated.

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