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Profitability of participation in control reserve market for biomass-fueled combined heat and power plants

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ABSTRACT

Increasing utilization of renewable energy results in a rising need for the allocation of control reserve, associated with the possibility to gain large remunerations in addition to spot market prices, in particular, for biomass-fueled combined heat and power (CHP) plants. Ancillary services in control reserve, however, require enlargement of storage volume due to needed decoupling of cogenerated power and heat. In order to evaluate participation profitability, two optimization models for daily unit commitment based on mixed-integer linear programming (MILP) are developed and applied, whereat the first solely focuses on spot market and only the second includes additional control reserve. Net present value (NPV) of the differences in result subsequently lays the basis for evaluation. Because Organic Rankine Cycle (ORC) technology has advantageous properties setting the scene for control reserve market, application is based on it as an example. To complete the study, other appropriated technologies are also considered. As a result, additional investment costs for storage enlargement are not covered by rising cash flow under current conditions of the ORC technology. Nevertheless, participation should not be dismissed for CHP plants in its entirety, since NPV shows a positive trend and profitability is already reached with little increase of electrical efficiency.

1. Introduction

1.1. Motivation

In order to promote a sustainable energy supply and benefit renewable energy technologies [1], the Renewable Energy Act (EEG) came into force in Germany in 2000 and was adapted by several other countries in meantime owing to its successful impact. While the act was initially aimed at giving investors possibility of minimizing their risk by a fixed price for feeding in power, its focus shifted towards a more demand-actuated and flexible power generation. As a consequence, plant operators are enabled access to spot and, in addition, control reserve market since 2012. At this, EEG leaves choice between the so-called market bonus scheme offering a minimum yield in height of above mentioned fixed remuneration and the direct participation without promotion [1]. Due to diminishing feed-in prices and uncertainty in further amendment of EEG, the latter becomes more and more attractive. At this, especially control reserve market might be a profitable and important source of revenues arising from growing importance of control reserve. Such participation, hence, seems to be an asset for technologies enabling flexibility and controllability of power generation and, thus, for biomass-fueled CHP plants under certain conditions.

Referring to the last aspect, CHP plants are characterized by efficient fuel exploitation by generating both power as well as heat. While market and storage opportunities for the generated power are manifold due to its physical properties, the heat must be used in the nearby proximity cotemporary. Thus, in order to fully participate in markets, the heat consumption must be decoupled from the power generation by implementing heat storage [2,3]. In this way, heat is provided when it is needed, while power can be sold independently on markets.

1.2. Previous considerations and objective of this work

In light of the previous orientation of the Renewable Energy Act and an absence of incentives for renewable energy operators to participate in markets, many previous papers addressing market participation focus only on the more general perspective. Such

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Mathematical symbols

CM	contribution margin
c_t	variable cost
c_F	fuel cost
$f_{ORC,aux}$	auxiliary power of plant referred to thermal output
$f_{stor,aux}$	auxiliary power of storage referred to in- and output
$f_{DH,loss}$	grid losses
$f_{stor,loss}$	storage losses
$\eta_{el,i}$	electrical efficiency factor
$\eta_{th,i}$	thermal efficiency factor
p_{th}	price thermal energy
$p_{el,t}$	price electricity for power consumption
$p_{da,\ t}$	price day-ahead spot market
$p_{cp,t}$	commodity price control reserve
$p_{cs,t}$	price capacity charge control reserve
P_t	electrical energy produced
$P_{da,\ t}$	load of electrical energy aimed for day-ahead spot market
$P_{cr,t}$	load of electrical energy aimed for control reserve market
$P_{cr,t,i}$	linearized part of load for electrical energy aimed for control reserve
$\dot{Q}_{dem,t}$	$_{dem,t}$load of thermal energy
$\dot{Q}_F$	$_F$quantity of fuel
$\dot{Q}_{th,t}$	thermal energy produced
$\dot{Q}_{th,cr,t}$	$_{th,cr,t}$thermal energy produced by control reserve
$\dot{Q}_{stor,in,t}$	$_{stor,in,t}$quantity of thermal energy for charging the thermal storage system
$\dot{Q}_{stor,out,t}$	$_{stor,out,t}$quantity of thermal energy for discharging the thermal storage system
$\dot{Q}_{F,i}$	$_{F,i}$linearized part of the total fuel quantity
$\dot{Q}_{F,max,i}$	$_{F,max,i}$maximum level of fuel for each linearized part of fuel quantity
r_t	revenue per hour
SOC	storage filling level
T	discrete time step of 1 h
T	optimization horizon for each planning day
$w_{cr,t}$	probability of request of control reserve
x	binary variable plant operation (with different indices)

papers do so without further specification of the CHP plant and, hence, without significant mention of renewable energies. While a portion of these papers concentrate on market participation in the spot market and the optimization of operation schedules, ignoring operators' prior spheres of influence within investment [4], other papers also attempt to answer the questions of optimal storage size and plant configuration [3,5]. Yet another group of surveys go into more detail, discussing the unit commitment of single plant components in light of spot market participation [6–8], since CHP plants are usually understood as a system comprised of the plant itself and other components such as a load peak boiler. Nevertheless, these papers often also fail to specify CHP plants in any greater detail. Consequently, the results have little meaning for renewable energy technologies.

Concentrating on biomass-fueled CHP plants, interest in market participation is increasing only gradually within research literature. However, the focus is currently on spot market participation and the question of the profitability of storage application, including the consideration of various storage and plant sizes [2,9]. A survey also taking into account the control reserve market in operation planning can be seen in the recent study of Hochloff/Braun [10], which shows how to incorporate a CHP plant based on biogas into spot and control reserve markets. However, the authors still lean onto the assured market participation of the market bonus scheme. Furthermore, the cogeneration of heat and power inherent to CHP is neglected as the survey concentrates entirely on profit-maximization in power generation.

In contrast, the approach presented in this paper will focus on the development of a model built upon direct market participation and a simultaneous consideration of heat and power production with the help of heat storage. In doing so, the emphasis in market participation is placed on the control reserve, or more precisely, on the positive tertiary control reserve.[1] Since the Organic Rankine Cycle (ORC) has properties advantageous for market participation, the technical fundamentals of this paper are based on its characteristics. At this point, the actual required minimum bidding capacity of the control reserve market is neglected. Referring to Andersen/Lund [12], in practice the operator of an ORC plant is only able to benefit from market participation by entering a CHP partnership. However, this will not be discussed in any further detail here.

Based on these assumptions, the article aims to give a general statement about the profitability of ancillary services in the control reserve for CHP plants, using the example of the year 2012 and the net present value (NPV). For this purpose, the scope of action is as follows:

Deducing a method to forecast control reserve prices in the short term.

Developing a model to determine the time and amount of participation in the spot and control reserve markets.

Examining the profitability of a possible extension of thermal storage in the case of control reserve market participation.

Furthermore, in an attempt to show the trend of the NPV, the functions indicating the efficiency of power and heat production will be adjusted. The power-to-heat ratio will be therefore shifted in order to suggest to what extent additional heat storage would be profitable for different biomass-fueled CHP technologies.

The statement about the profitability and the trend are achieved by means of the maximization of the daily contribution margin for a period of one year. Mixed-integer linear programming (MILP) will be applied. To allow an evaluation, two separate optimization models will be developed. While the first model neglects participation in the control reserve, the second model will take it into account. Subsequently, the results from both models will be compared.

The outline of the paper is as follows: In section 2 the applied approach is explained in detail. In this context, the method and parameter estimation of the profitability measurement as well as fundamentals of market participation and tertiary control reserve price modeling are first laid out, followed by an explanation of technical fundamentals and bounds. The section concludes with the derivation of both optimization models. The results are presented in section 3. In order to give a better understanding, the results from the ORC plant and the trend according to a ratio shift

[1] An overall survey of implementation and modeling approaches for the spinning and non-spinning reserve with respect to the control reserve market was carried out by Gonzalez et al. [11].