BIOMASS AND BIOENERGY 65 (2014) 125–135

Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

Optimizing biogas plants with excess power unit and storage capacity in electricity and control reserve markets

Patrick Hochloff [a,*], *Martin Braun* [a,b]

[a] *Fraunhofer-Institute for Wind Energy and Energy System Technology, Königstor 59, 34119 Kassel, Germany*
[b] *University of Kassel, Germany*

ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form
16 December 2013
Accepted 19 December 2013
Available online 8 January 2014

Keywords:
Biogas plants
Gas storage
Unit commitment
Mixed-integer linear programming
Electricity market
Ancillary services

ABSTRACT

Increasing shares of intermittent power sources such as solar and wind will require biomass fueled generation more variable to respond to the increasing volatility of supply and demand. Furthermore, renewable energy sources will need to provide ancillary services. Biogas plants with excess generator capacity and gas storages can adapt the unit commitment to the demand and the market prices, respectively. This work presents a method of day-ahead unit commitment of biogas plants with excess generator capacity and gas storage participating in short-term electricity and control reserve markets. A biogas plant with 0.6 MW annual average electric output is examined in a case study under German market conditions. For this biogas plant different sizes of the power units and the gas storage are compared in consideration of costs and benefits of installing excess capacity. For optimal decisions depending on prices, a mixed-integer linear programming (MILP) approach is presented.

The results show that earnings of biogas plants in electricity markets are increased by additional supplying control reserve. Furthermore, increasing the installed capacity from 0.6 MW to 1 MW (factor 1.7) leads to the best cost–benefit-ratio in consideration of additional costs of excess capacity and additional market revenues. However, the result of the cost–benefit-analysis of installing excess capacity is still negative. Considering the EEG flexibility premium, introduced in 2012 in the German renewable energy sources act, the result of the cost–benefit-analysis is positive. The highest profit is achieved with an increase of the installed capacity from 0.6 MW to 2 MW (factor 3.3).

1. Introduction

In Germany, the renewable energy resources act (EEG) pays biogas electricity generators a fixed feed-in tariff and optionally, since 2012, premiums for the market participation [1]. The fixed feed-in tariff develops biogas plants with power unit sizes adapted to the production rate of biomass fermentation. High annual utilization of the equipment is required for economic plant operation [2–4], e.g. 7760 [3] or 8200 [4] full load operating hours per year. In this mode, electricity generation is nearly constant, with a market value equivalent to base load market prices.

In the future, flexible biogas plants will be needed that adapt their electricity generation to demand. The EEG

* *Corresponding author.*
E-mail address: patrick.hochloff@iwes.fraunhofer.de (P. Hochloff).
0961-9534/$ – see front matter
http://dx.doi.org/10.1016/j.biombioe.2013.12.012

determines goals for the increase of renewable energy sources until 2050. Scenarios of those future energy systems show high shares of biomass and volatile wind and solar energy in electricity generation. Dynamic simulations of these scenarios show that thermal power plants including biomass plants will operate with reduced full load hours adapted to the volatile power generation for efficient load covering [5]. Therefore, it is assumed that biogas plants with continuous biogas production and over-sized power units and gas storage will be operated flexibly, according to supply and demand.

Biogas is more valuable if it is used to generate electricity at times when the market needs it. In 2012, the mean German EPEX base load price was 42.60 € MWh^{-1} and the mean peak load price was 48.51 € MWh^{-1} [6]. If a biogas plant was able to produce the same electric energy in half the time, from 8:00 am to 8:00 pm instead of over a 24 h period, the electricity would be worth an extra 5.91 € MWh^{-1}. This mean difference between daily base and peak load prices has been declined from 7.97 € MWh^{-1} in 2009 to 6.47 € MWh^{-1} in 2010 and 6 € MWh^{-1} in 2011.

1.1. *Market participation of biogas plants*

The EEG added new options of biogas electricity payments in order to prepare biogas plants to future requirements. Since 2012, the EEG has introduced premiums to make biogas plants participate at electricity markets (market premium) and invest in plant upgrades for flexible power generation (flexibility premium). The market premium compensates for the difference between the feed-in tariff and the base load market price. The flexibility premium is a defined payment for the excess power unit capacity of a biogas plant if the plant participates in electricity markets [1]. It is assumed that the excess capacity is used efficiently to generate more market revenues than would be obtained at the base load price. Therefore, the technical ability to produce electricity flexibly is paid for with additional market revenues and the flexibility premium.

1.2. *Electricity and control reserve markets*

Electricity spot markets for Germany are organized by EPEX SPOT SE, where a single day-ahead auction at 12:00 CET determines a single market clearing price for each hourly contract. In addition, there is a continuous trade of contracts for each hour, and for every quarter hour. The continuous trade of contracts for the next day starts after the day-ahead auction (15:00 CET and 16:00 CET, respectively) and ends 45 min before contract settlement [7].

In addition to the electricity markets, there are markets that organize frequency control. The German transmission system operators (TSO) organize a common auction market to procure control reserve that is entered into force by Ref. [8] for primary control reserve, [9] for secondary control reserve and [10] for tertiary control reserve. The purchased control reserve capacity must be held available by the vendors and is activated by calls from the TSO in order to regulate system frequency. A survey of the primary, secondary and tertiary control reserve products is contained in Table 1. The merit order auction determines the marginal bid which is needed to meet demand. The payment of accepted bids is the capacity price of each bid [8–10]. Secondary and tertiary reserve contracts contain also an energy price for activated reserves which is not considered at the auction [9,10].

1.3. *Optimization of market revenues with biogas plants*

Biogas plants share many characteristics with natural gas combined heat and power plants (CHP) as both use internal combustion engines or gas turbines. Therefore, our optimization approach is based on work done showing how a CHP can be scheduled for optimal market participation.

The scheduling of CHP plants with heat storage is presented in Ref. [11]. The scheduling of CHP plants especially with gas turbines is presented in Refs. [12–15] and with internal combustion engines in Refs. [15–18].

The unit commitment and generation dispatch of CHP plants is solved with mixed-integer linear programming (MILP) for example in Refs. [12–14,16,17,19–22]. Efficient modeling for MILP of specific thermal plant details e.g. characteristic curves, is presented in Ref. [23].

The provision of control reserve by a CHP plant is considered in Refs. [14,22]. In Refs. [14], the commitment of control reserve of individual units, and the total amount of control reserve, is determined before solving the unit commitment and generation dispatch with MILP. In Ref. [22] the requirement of long term contracts including control reserve is considered in short-term planning.

1.4. *Objective of work*

The objective of this work is to determine the benefit of optimizing biogas plants with excess capacity in short-term

Table 1 – Primary, secondary and tertiary control reserve products [8–10].

	Primary	Secondary	Tertiary
Auction times	Weekly on Tuesday, 15:00 CET	Weekly on Wednesday, 15:00 CET	On workdays (Mo.–Fr.) 10:00 CET
Tradable products	1 product: symmetric positive and negative reserve	4 products: positive and negative reserve separated each for peak and off-peak time	12 products/day: positive and negative reserve separated; each for six time slots/day
Product length	24 h/day for 7 days	Peak time products: from 8:00 to 20:00 CET from Monday to Friday Off-peak time products: from 00:00 to 8:00 and from 20:00 to 24:00 CET from Monday to Friday and from 00:00 to 24:00 CET on Saturday and Sunday	4 h