Renewable and Sustainable Energy Reviews 29 (2014) 383–393

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Review of concepts for a demand-driven biogas supply for flexible power generation

Henning Hahn [a,*], Bernd Krautkremer [a], Kilian Hartmann [b], Michael Wachendorf [c]

[a] Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), Division Bioenergy System Technology, Königstor 59, D-34119 Kassel, Germany
[b] Department of Engineering Science, University of Applied Sciences Aschaffenburg, Würzburger Str. 45, D-63743 Aschaffenburg, Germany
[c] Department of Grassland Science and Renewable Plant Resources, University of Kassel, Steinstr. 19, D-37213 Witzenhausen, Germany

ARTICLE INFO

Article history:
Received 2 May 2013
Received in revised form
14 August 2013
Accepted 24 August 2013

Keywords:
Biogas
Flexible biogas production
Biogas storage
Biogas upgrading
Balance power
Renewable energy system

ABSTRACT

The share of electricity produced from renewable energy is constantly increasing in Germany and worldwide. The transformation to an electricity system based on renewable sources is characterised by an increasing need for balancing power in order to compensate power supply from fluctuating sources, such as solar or wind. Biomass, more precisely energy from biogas, has the potential to generate electricity flexible on-demand. A demand-driven biogas production is vital for balancing power generation and can generally be achieved by biogas storing or flexible biogas production concepts.

This study analyses and reviews both concepts regarding their ability to facilitate a biogas supply for short-term and long-term balancing power generation. Results show that a demand-driven biogas supply based on a biogas storing concept is, due to the fast availability of biogas (i.e. biomethane), suitable for the generation of positive secondary and tertiary balancing power. Whereas, long-term balancing power can be provided by flexible biogas production as well as by biomethane, which was injected and stored in the natural gas grid. Basically all reviewed biogas supply concepts that facilitate a shutdown of electricity generation by storing or stopping the biogas production can additionally provide negative balancing power.

Contents

1. Introduction . . . 2
2. Legal background of flexible power generation with biogas in Germany . . . 2
3. Concepts for a demand-driven biogas supply . . . 3
  3.1. Biogas storing concepts . . . 3
    3.1.1. On-farm biogas storage . . . 3
    3.1.2. Biogas upgrading and biomethane grid injection . . . 3
  3.2. Concepts for flexible biogas production . . . 4
    3.2.1. Variable substrate feeding . . . 4
    3.2.2. Adapted biogas plant configurations . . . 5
4. Discussion . . . 6
5. Conclusions . . . 8
Acknowledgements . . . 8
References . . . 8

Abbreviations: AD, Anaerobic digestion; ADM No. 1, Anaerobic digestion model number 1; BImSchG, German federal pollution control act; CH_4, Methane; CHP, Combined heat and power plant; CO_2, Carbon dioxide; CSTR, Continuously stirred tank reactor; EC, European commission; EEG, German renewable energy act – "Act on granting priority to renewable energy sources"; ENWG, German law on energy management; FIT, Feed in tariff; FPR, Flexibility premium; H_2, Hydrogen; H_2S, Hydrogen sulphide; H-Gas, High quality natural gas; IFBB, Integrated generation of solid fuel and biogas from biomass; km, Kilometre; L-Gas, Low quality natural gas; MMP, Management premium; Mol%, Per cent of molar mass; MP, Market premium; MV, Market value; oDM, Organic dry matter; PF, Press fluid; RE, Renewable energy; ReBi, Regelbare Biogasanlage (Dispatchable biogas plant); RG, Raw biogas; rs-CH_4, Specific methane yield; RV, Reactor volume; vol%, Per cent of volume; VS, Volatile solids; WS, Whole crop silage; y-CH_4, Cumulative methane yield

* Corresponding author. Tel.: +49 5617294261.
E-mail address: henning.hahn@iwes.fraunhofer.de (H. Hahn).

1364-0321/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.rser.2013.08.085

1. Introduction

The proportion of renewable energy (RE) production referring to the total energy production has strongly grown in Germany and worldwide during the last years [1,2]. In 2012 the national German gross power generation was 617 TWh; about 135 TWh (22%) were produced by renewable sources [3], which are considered as clean and sustainable energy that helps to mitigate climate change [4]. Further expansion of power generation from RE in Germany is targeted. Thus, the German government adopted an ambitious energy concept including a guideline for an overall strategy for the transformation of the energy supply system. The concept aims to raise the share of RE sources up to at least 35% in gross electricity consumption by the year 2020 and to more than 80% by the year 2050 [5].

Since water and biomass are limited resources the largest contributions to highly RE systems will come from wind and solar power [6,7]. However, wind and solar power plants are characterised by strong temporal fluctuations, which in turn cause a variable power generation, with an only partly predictable availability. Important shares of their supply remain stochastic [8]. Due to high forecast deviations it had been necessary to curtail the electricity production from RE generators in some regions with too much surplus electricity production from wind and sun (legally based on sec 11 EEG [9] and sec 13 (2) ENWG [10] cp. [11–13]), even though Germany's share of RE power production is currently rather small. Considering the goal of the German Government of phasing out the use of fossil fuels and the obligation through the Directive of the European Commission 2009/28/EC [14], an efficient utilisation of power from renewable sources is important, thus a cessation of RE generators should be avoided if possible.

Integrating large amounts of intermittent energy sources in energy systems poses balancing challenges. In this respect, electricity from biomass, particularly from biogas, offers the advantage of high availability as well as high predictability [15]. Beyond that, biogas respective the necessary input biomass can be stored and electricity can be generated demand-driven, independent from climatic influences (sun and wind), to balance the intermittent power production from weather-driven RE [16]. Thus, power from biomass, more precisely from biogas, is able to contribute to the integration of large proportions of RE in future energy systems [17].

In numerous studies for a pan European energy system [7,8, 18–20] experts have analysed the necessary balancing power in partly or fully RE systems. In this context Heide et al. [21] have analysed the required energy storage capacity for a simplified 100% wind and solar power generation scenario with 400–480 TWh per year. This would exceed the available storage capacity of pumped-hydro and compressed-air storages in Europe [18,22]. A study published by the German Federal Environment Agency analysed the residual basic load for a 100% RE supply in Germany, based on data of the meteorological year 2009. The residual basic load was calculated as the difference between basic load and the generation of RE, without electricity from biomass. The study revealed temporary deficits with a maximum of 50 GW and a yearly amount of 53 TWh that has to be balanced [23] by stored electricity or dispatchable energy generators.

Energy storages and their characteristics have been comprehensively analysed in the literature, e.g. in Refs. [24–27]. Storage capacity has become already an important issue and will become even more important in the future as the share of intermittent energy sources is growing. However, storing electricity is always connected with efficiency losses through energy conversion steps. Furthermore it represents a cost intensive balancing method [28]. Strategies to mitigate necessary storage capacities in RE systems are to enhance and expand the existing power grid [8,29,30] with interconnections to neighbouring countries [18,21], as well as to activate flexible electricity demand options, such as heat pumps [31] or electric vehicles [32,33]. Moreover, generation management through dispatchable power plants for instance as hydro pump plants, gas turbines and biogas-driven power plants will become more important [34].

In Germany there are currently more than 7300 biogas plants with an installed electrical capacity of about 3 GW in operation. In 2012 German biogas plants produced electricity of approx. 22 TWh, most of them by more than 7000 full load hours per year [35,36]. Depending on the requested long-term or short-term balancing power the yearly full load operation hours for instance could be reduced to 4000 or 2000 h/yr. This in turn would increase the installed balancing capacity from biogas to 6 or 12 GW and in this way contribute to reduce necessary energy storage capacities. A demand-driven biogas supply is vital for balancing power generation and can basically be realized by biogas storing or flexible biogas production concepts, as well as a combination of both. Since electricity from biogas had not been used to balance fluctuations of intermittent RE in the past, these concepts are still at an early stage of their technical implementation to supply power generation systems demand-driven with biogas. This study aims to analyse the balancing services that could be available by the following concepts: (i) on-farm biogas storages, (ii) injected biomethane and (iii) a flexible biogas production.

2. Legal background of flexible power generation with biogas in Germany

In Germany, electricity from RE is promoted through feed-in tariffs that guaranteed fixed prices for 20 years. Feed-in tariffs have been proven to be a successful instrument for promoting the expansion of biogas plants in Germany [1] (cf. [37,38]), that are currently producing more than 50% of the total biogas production in Europe [35,36]. The vast majority of it is utilised for electricity production in combined heat and power plants (CHP) as baseload power [1,39,40]. However, substituting a centralised energy system based on large scale baseload power plants with a mixture of small-scale, decentralised RE with a high share of intermittent energy carriers, poses challenges for the efficiency and security of energy supply [41,42]. To tackle these problems it is not enough to substitute fossil energies with RE sources; a successful energy transformation requires an expansion of the grid and storage capacities, as well as an improvement in energy efficiency and savings, but there also need to be incentives for a demand-oriented and efficient deployment of existing plant capacities as well as for an investment in increasing the flexibility of electricity production. A demand-driven electricity production from biogas or other RE carriers had, in the past, not been supported by the previous versions of the German Renewable Energy Act (Act on Granting Priority to Renewable Energy Sources, known by its German acronym "EEG") [43,44]. Consequently, electricity from biogas had not been produced on-demand, due to necessary additional investment in the biogas plant technology (i.e. for the expansion of the biogas storage and CHP capacity) and missing economic incentives. However, biogas driven generation units are principally suitable for a demand-driven electricity generation, due to their necessary short start-up periods and high controllability, which Hartmann et al. [45] analysed and tested.

Since January 2012, incentives for a market-oriented and demand-driven power generation from biogas have been implemented in the adopted version of the EEG [9]. Whereas in the past biogas plant operators received a fixed price (according to the feed-in tariff scheme of the EEG 2009 [46]) for each kilowatt hour fed into the electricity grid, the newly implemented market