



Contents lists available at ScienceDirect

Energy

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

Economic assessment of a solid oxide fuel cell system for biogas utilization in sewage plants

Karl Hauptmeier, Mathias Penkuhn*, George Tsatsaronis

Institute for Energy Engineering, Technische Universität Berlin, Marchstr. 18, D-10587 Berlin, Germany

ARTICLE INFO

Article history:

Received 12 August 2015

Received in revised form

13 April 2016

Accepted 19 May 2016

Available online xxx

Keywords:

Economic analysis

Biogas

Cogeneration

SOFC

ABSTRACT

Fuel cells are likely to make their market introduction through high-efficiency applications in niche markets. A possible market for SOFC systems is therefore the utilization of biogas from sewage treatment plants. However, the feasibility of fuel cell applications crucially depends on the gas cleaning system. A system layout for SOFC integration is derived from an existing fuel cell system for biogas utilization, providing a feasible design for gas cleaning for contaminant removal and data on different operation regimes. The resulting SOFC plant provides electricity and heat for on-site usage at the sewage plant by cogeneration. The SOFC system is then analyzed at system level regarding its economic viability compared to a conventional CHP system. Costing for the different system components is made using cost data and literature-based estimates. Different design studies concerning system size and a subsequent sensitivity study concerning decisive economic parameters are used to provide robust decision measures. The study shows that economic feasibility of an SOFC system for biogas utilization can be achieved without subsidies in the near future if SOFC system prices are reduced from 7000 to about 3000 EUR/kW_{el}. It is further shown that smaller SOFC systems are preferable due to their current economies of scale.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Fuel cells offer the possibility of direct conversion of chemical energy to electric energy by electrochemical pathways. By avoiding the limitations of conventional power generation technologies, fuel cells offer a remarkably high efficiency combined with low environmental impact [1,2]. These advantages have led to an increased industrial and governmental attention, thus providing fuel cell technology research and development (R&D) with increased funding [3–6] and stimulating international cooperation like IEA's advanced fuel cells and hydrogen implementing agreements [7]. But, even though much money was spent on R&D during the last 50 years, the commercialization is still delayed and the economic feasibility not yet demonstrated [5,8–10].

Based on the current status and future R&D needs, it is unlikely that fuel cells will make their market entry in the large-scale power generation sector with more than 10 MW per plant. The current

market conditions in this segment do not favor fuel cell systems in general, due to the lack of subsidies and alternative evaluation methods to determine the cost of electricity [11]. Therefore, a market introduction in technological niches is more likely. In such market sections the technology can be tested, while it can be more expensive than the technology it replaces, if additional advantages like higher efficiencies are offered.

Among the various fuel cell technologies available, the solid oxide fuel cell (SOFC) technology offers various advantages, especially in stationary applications. High system availability time, flexibility of power generation, high efficiency, even in part-load operation, and low specific emissions [1,12] are just a few to mention.

A major challenge to exploit further market potential is the reduction of production cost. Looking at today's situation, small-scale SOFC demonstrators [5,13–15] are already in use. These units contribute to cost reduction by three major factors: innovation (economies of scope), economies of scale and the learning curve effect [16,17]. Therefore, these units help taking the transition step between pilot and very early commercial stages and the production at commercial scale.

If these effects are taken into account, then a possible market

* Corresponding author.

E-mail addresses: contact@karlhauptmeier.eu (K. Hauptmeier), mathias.penkuhn@iet.tu-berlin.de (M. Penkuhn), tsatsaronis@iet.tu-berlin.de (G. Tsatsaronis).

entry for SOFCs can be found in small (100 kW–5 MW) combined heat and power (CHP) applications [9], where the investment cost difference to conventional technologies like gas turbines and gas engines becomes smaller. Likewise, the operating costs are lower due to higher efficiencies. Hence a typical area of fuel cell implementation, apart from domestic uses, can be found in the processing of low calorific gas which is used in small-scale power generation. Accordingly, steel production gases (coke gas, blast furnace gas and converter gas) [18] or sewage treatment gases (biogas) [19,20] can be advantageously processed by fuel cells.

The high methane content of biogas makes it particularly suitable for high-efficiency utilization in SOFCs [21]. During the past two decades extensive research has been conducted to prove the feasibility of SOFC application in this area. Detailed simulation models have been developed [22,23] for conducting technological studies concerning fuel usage, system layout and optimal operation parameters. Additionally, the effect of biogas contaminants and their removal for secure SOFC operation has been addressed [24,25]. Assessing the general question of technoeconomic feasibility, recent studies [26–28] have shown, that mature SOFC systems are generally favorable compared to conventional technologies for biogas utilization.

Sewage treatment plants offer a big market potential due to their large number of existing plants (approximately 11,000 sites in Germany alone, of which more than 150 have a population equivalent larger than 50,000 [29]). Approximately, a population equivalent of 90,000 is needed to supply a 200 kW_{el} SOFC power plant with sufficient biogas [19] rendering a large set of potential small-scale sites. It seems viable that SOFC technology can therefore find its niche market in this segment due to its advantages of high-efficiency power and heat generation being tailored to the inherent needs of sewage treatment plants. Moreover, pilot projects in this segment could significantly increase the production volume of producers and thus significantly decrease cell production costs through economies of scale and scope.

Based on the large potential of biogas utilization, the present study assesses the economic potential of using SOFC systems in contrast to conventional CHP systems for biogas utilization. Using data from an existing fuel cell plant for biogas utilization, the questions concerning system layout, gas cleaning options and cost data are addressed explicitly. Based on these data the question which system price makes SOFCs economically favorable to conventional solutions is answered with reduced uncertainty.

2. Methodology

In this paper, the net present value method is used to assess the economic measures of the biogas utilization solutions. After a short outline of the method, the approach for analyzing the SOFC and conventional CHP systems is developed.

2.1. Net present value and net present cost

The net present value method is a dynamic investment calculation method with the purpose to find the most favorable investment out of a variety of possible options. The option with the highest net present value (NPV) or the lowest net present cost (NPC) is thereby the most profitable one [30].

The NPV of a project is calculated as the sum of the present values (PV) of all future cash flows (F). The present value describes the value of future earnings and expenses in the present. To calculate the present value of a certain future cash flow, it has to be discounted. Here all net present values refer to net present costs since no revenues are considered.

$$NPV = NPC = \sum_{k=0}^m PV_k = \sum_{k=0}^m \frac{F_k}{(1+i)^k} \quad (1)$$

The variable n represents the number of time periods and i is the calculation interest rate or discount rate.

To calculate the PV of cash flows that occur annually, such as revenues or operational expenditures, the capital recovery factor CRF [31] is helpful. With the annuity A being the constant annual cash flow over the given time period n , the PV of all these cash flows can be calculated using the following equation.

$$PV = A \cdot \left(\frac{i \cdot (1+i)^n}{(1+i)^n - 1} \right)^{-1} = \frac{A}{CRF} \quad (2)$$

The NPV method is a useful tool to make a sound investment decision, taking into account future income and investments as well as the time value of money [30]. Nonetheless, the net present value analysis is bound to monetary terms. Benefits of fuel cell systems like prestige, low environmental impact and know-how, cannot be assessed in monetary terms and thus not be reflected in the NPV calculations [19].

2.2. Approach to analyze the utilization of biogas from sewage plants

Since sewage treatment is typically either a public service or a unit within an industrial plant, it cannot be justified by its profitability. Thus, the decisive question is how this service can be provided with the least possible NPC.

The calculation of the NPC is separated into five different parts. The NPC calculations are taking into account the capital expenditures (CAPEX), the operational expenditures (OPEX), the cost of externally provided electricity (CoE), the cost of externally provided heat (CoH), and possible subsidies. Even though the cost of the required additional electricity and heat are generally considered as a part of the OPEX, they are reported separately due to their high influence on the NPC. An overview of the calculation procedure is shown in Table 1.

3. System description

The system used for the economic assessment of SOFC integration in sewage treatment plants is derived from an existing and running fuel cell system [19]. It is based on phosphoric acid fuel cell (PAFC) technology and has been extensively tested at the sewage treatment plant at Cologne-Rodenkirchen [19]. A competitive option would be the installation of a conventional CHP system with a gas engine, which is used for comparative purposes.

Table 1
Simplified model for NPC calculations.

Investment cost of the power system		CAPEX
Investment cost of the gas cleaning system		
Cost of maintenance	+	OPEX
Cost of service and inspection		
Labor		
Cost of externally provided electricity	+	CoE
Cost of externally provided heat	+	CoH
Supplementary payments (based on the KWKG)	–	Subsidies
	=	NPC

Download English Version:

<https://daneshyari.com/en/article/5477143>

Download Persian Version:

<https://daneshyari.com/article/5477143>

[Daneshyari.com](https://daneshyari.com)