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ScienceDirect

Energy Procedia 126 (201709) 421–428

Energy Procedia

www.elsevier.com/locate/procedia

72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017, 6-8 September 2017, Lecce, Italy

Performance analysis of a micro CHP system based on high temperature PEM fuel cells subjected to degradation

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Abstract

Micro Combined Heat and Power (microCHP) systems based on High Temperature Polymer Electrolyte Membrane (HTPEM) fuel cells is a promising technology allowing to produce electricity and heat with very high efficiency and low emissions also for small power systems. Polybenzimidazole (PBI) based HTPEM fuel cells, thanks to their high CO tolerance, allow the use of fuels other than pure hydrogen by means of a simplified fuel processing unit. However, their relatively low performance and performance degradation rate are still issues to be overcome in order to allow commercialization. In this work, an energy simulation model developed by the authors in a previous research work, has been improved taking into account the degradation of the fuel cell stack in order to assess the performance of the system over long period of operation. The fuel cells performance degradation over time has been implemented on the basis of experimental data obtained by the authors and on data found in literature. The performance of the system has been studied in different configurations that include the introduction of a lithium battery storage in addition to the fuel cell stack.
System parameters, such as electrical and thermal energy production, import/export of electricity and primary energy savings have been calculated and compared for different system configurations. Results show that battery integration can improve system performance and that the effect of fuel cell degradation reduces the electricity production. The effect on overall efficiency can be mitigated if heat is recovered.

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Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association

Keywords: PEM fuel cell; hydrogen; lithium battery; storage systems

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Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association
10.1016/j.egypro.2017.08.198

1. Introduction

Fuel cells based CHP systems have the great advantage to maintain good electrical efficiencies for small size plants and during partial load operation.
Various types of fuel cells exist but, for CHP applications, the market is nowadays contended by three main technologies: SOFC (Solid Oxide Fuel Cells), LT-PEM FC (Low temperature Polymer Electrolyte Fuel Cell) and HT-PEM FC (High temperature Polymer Electrolyte Fuel Cell).
SOFC systems, have the potential of a very good electrical efficiency, good contaminants tolerance and they can easily be fuelled with methane but they still show problems in materials durability especially during variable load operation and start-up process [1].
LT-PEM fuel cells are nowadays the most used technology for CHP systems due to their good electrical efficiency (almost 40%) and a lifetime that can be longer than 20 000 h. This technology owes its success mainly to the Japanese Ene-Farm project that brought to the installation of more than 100 000 residential fuel cell micro CHP units [2].
However, in the last few years, a promising alternative to LT-PEM fuel cells seems to be represented by HT-PEM fuel cells systems, having the main advantage to bear CO contamination up to 3% [3] allowing an important simplification of the fuel processing. Another important system simplification is obtained thanks to the elimination of the humidification process that, for HT-PEM, is not required. Moreover, operating at high temperature, the heat recoverable for cogeneration is of better quality and the heat recover system is simplified [1].
The energy performance analysis of HT-PEM system considering typical domestic electric and thermal load profile can be done using energy simulation models. In literature there are many examples for these models. For example, in [4] a high temperature PEMFC-based micro-CHP system similar to the one studied in this paper is considered. The overall efficiency is higher than 83%, with 28% of net system electrical efficiency and 55% of net system thermal efficiency. Fuel cell stack efficiency is 38%. The same authors, in [5], implemented a genetic algorithm to optimize the system and they improved the electrical efficiency up to 41% while thermal efficiency and total system efficiency were respectively 50% and 91%. A major problem for this type of fuel cells is the degradation rate that is higher than LT-PEM FC. When analysing CHP systems, performance over long period is an important factor and, therefore, degradation should be considered. In [6] the authors implement a simulation model of a HT-PEM micro CHP system and validate it with experimental data and use the model in [7] to analyse the system performance over one year of operation. As for the system degradation modelling, in [8], both the stack and reformer long term performance have been considered. A multi-objective optimization approach has been introduced in order to find the optimal operating parameters within the first 15 000 hours of operation while considering the impact of the degradation. In this work, an energy simulation model developed by the authors in a previous research work [7], has been improved taking into account the degradation of the fuel cell stack in order to assess the performance of the system over long period of operation. System parameters, such as electrical and thermal energy production, import/export of electricity and primary energy savings have been calculated and compared for different system configurations.

2. Simulation model description

2.1. System layout

The system is composed of a 1 kW_{el} fuel cell system, which encompasses a fuel processor and a HTPEM fuel cell stack, and a 3 kWh lithium battery pack. An auxiliary boiler is used when heat from the fuel cell system is not sufficient for providing the heating demand. Fuel cell system, battery pack and grid are electrically connected by means of a power conditioning system. The fuel processor is composed of a steam reforming reactor based on nickel catalyst and a single CO purification stage. A catalytic burner is used to supply heat for the reforming reaction. Fuel sulphur compounds are removed by means of a dry desulphurization unit before fuel enters the system. The HTPEM fuel cell stack is based on a commercial PBI MEA fuel cell (BASF Celtec P1000). The battery pack is composed of 3.2 V, 40 Ah Li-FePO4 battery cells. Battery performances are experimentally investigated in [9]. Additional information on the system were presented by the authors in [10]. In order to connect the fuel cell to the battery pack

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