Applied Energy 178 (2016) 415–421

Contents lists available at ScienceDirect

Applied Energy

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

Start-up and operation characteristics of a flame fuel cell unit

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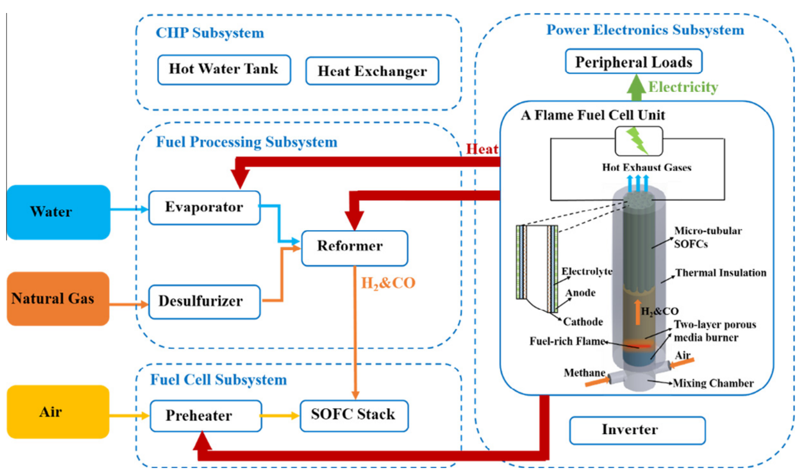
HIGHLIGHTS

- A novel micro-CHP system using the flame fuel cell for black start-up.
- Integrating a porous media burner with a micro-tubular SOFC.
- Start-up and operation characteristics of a flame fuel cell unit.

GRAPHICAL ABSTRACT

A micro heat and power cogeneration system with black start-up capability was proposed by integrating a flame fuel cell. A flame fuel cell unit with multi-cell configurations is potential to provide heat and power simultaneously for micro-CHP systems to start up without external energy source.



ARTICLE INFO

Article history:
Received 2 April 2016
Received in revised form 25 May 2016
Accepted 17 June 2016

Keywords:
Flame fuel cell
Black start-up
Combined heat and power
Micro-tubular SOFC
Porous media burner

ABSTRACT

This work aims to investigate a black start-up process for micro cogeneration (combined heat and power, CHP) systems based on solid oxide fuel cells (SOFCs). A novel micro-CHP system concept using a flame fuel cell (FFC) for start-up is proposed. An FFC unit is experimentally implemented and studied by integrating a porous media burner with a micro-tubular SOFC. The FFC is demonstrated to start up within seconds with the fuel-rich combustion of a methane-air mixture. The porous media burner acts as a non-catalytic fuel processor for the SOFC with a maximum methane reforming efficiency of 49%. The flame fuel cell performance is tested for various equivalence ratios at a fixed inlet gas velocity of 0.15 m/s. The power reaches a significant value of 1.5 W at 0.7 V with a single fuel cell when operating with a fuel-rich flame at the equivalence ratio of 1.6. A flame fuel cell unit with multi-cell configurations has the potential to provide heat and power simultaneously for micro-CHP systems during the start-up process without an external energy source.

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http://dx.doi.org/10.1016/j.apenergy.2016.06.067
0306-2619/© 2016 Published by Elsevier Ltd.

1. Introduction

Micro combined heat and power (CHP) systems based on fuel cells are promising energy technologies that can reduce CO_2 emissions and meet the energy demand of residential dwellings [1–4]. Proton exchange membrane fuel cells (PEMFC) have been widely studied for the application in a micro CHP system [5–8]. Barelli carried out an energetic–exergetic analysis of a residential CHP system based on PEMFC [9]. The dynamic characteristic of the PEMFC-based CHP systems was also studied [10]. Compared to the PEMFC, solid oxide fuel cells (SOFCs) are advantageous for their high efficiency and elimination of expensive catalysts. Consequently, micro-CHP systems based on SOFCs are being increasingly studied and implemented in the domestic sector [11–13]. Alston studied a cogeneration system based on SOFCs with the intention of supplying 30 kW of hot water and 500 W of power for domestic cogeneration [14]. Liso analyzed the impact of the heat-to-power ratio for a SOFC-based mCHP system for residential application in different climate regions in Europe [15]. Japan is the leading country in the micro-CHP system sector where a typical micro-CHP system, the ENE-FARM-S has been commercialized with a power generation efficiency of 46.5% [12].

The typical layout of such micro-CHP systems is shown in Fig. 1(a). The system consists of a fuel processing subsystem, a power electronics subsystem, a fuel cell subsystem and a CHP subsystem [16]. Natural gas or other hydrocarbon fuels are converted to syngas in the fuel processing subsystem through various reforming processes; steam reforming is the most widely used process. Next, the chemical energy of the syngas is converted to electricity in the fuel cell subsystem. The CHP subsystem uses the waste heat from the fuel cell stack and fuel processing subsystem to supply heat for the users. The power electronics subsystem is used for monitoring and controlling the system operation and contains various devices that require electrical power, i.e., sensors, inverters and regulators. Before the normal operation of a CHP system, an operation load must be supplied to these peripheral loads for system start-up.

Although numerous studies have been carried out to optimize the operation performance of SOFC micro-CHP systems [17–19], few have focused on the energy demand during the system start-up process. In current micro-CHP systems, the power needed by the peripheral loads during start-up is typically provided by the power grid. However, because many micro-CHP systems aim at distributed applications where the power grid is not available or is not sufficiently reliable [20], a micro-CHP system with black start-up ability is needed. Currently, electrical storage devices such as a battery or an electrochemical capacitor are used to provide electrical power for the system to start up without the power grid [21]. For example, the ENE-FARM-S utilizes a storage system to store excess energy; the battery can provide power for an off-grid system start-up [12]. Nevertheless, such electrical storage devices may lose electrical energy because of self-discharge; as a result, insufficient power is available to supply the operational load of the system and the whole system will not start. In other cases,

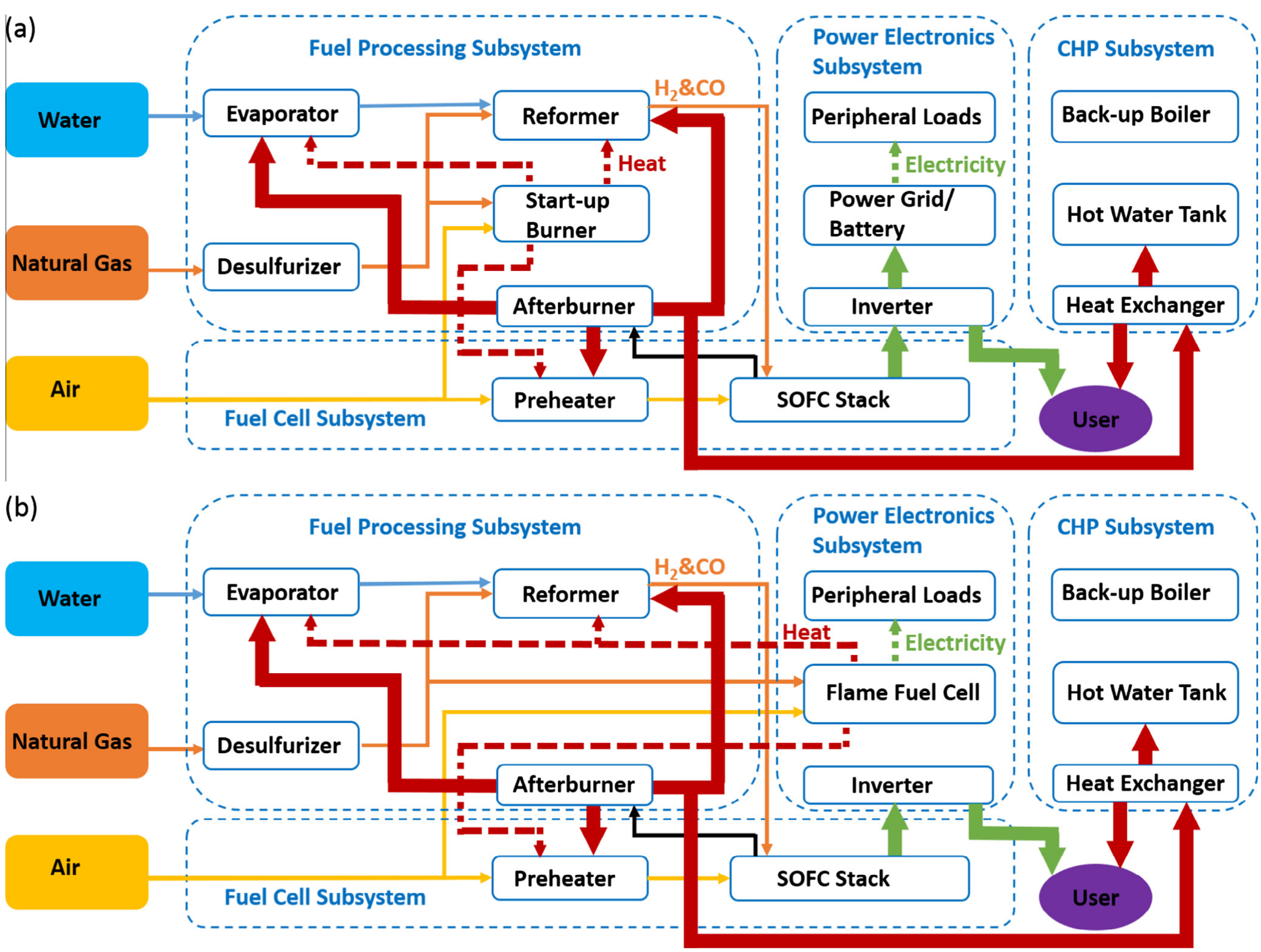

Fig. 1. Layout of micro-CHP SOFC systems. (a) Traditional system. (b) Novel system utilizing FFC.