Applied Energy 216 (2018) 620–633

Contents lists available at ScienceDirect

Applied Energy

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

Experimental and numerical analysis of a SOFC-CHP system with adsorption and hybrid chillers for telecommunication applications

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HIGHLIGHTS

- A combined experimental and numerical investigation of a novel small size multi-generation system is presented.
- Experimental characterization of the SOFC-CHP and thermally driven systems used is reported.
- TRNSYS model developed evidenced up to 110 MWh/y energy savings in comparison to traditional systems.

ARTICLE INFO

Keywords:
Multi-generation
SOFC-CHP
CCHP
Adsorption chiller
Cascade chiller
Telecommunication shelter

ABSTRACT

This paper reports about the combined experimental and numerical investigation of a novel small size multi-generation system, for electric (i.e. < 10 kW) and cooling (i.e. < 20 kW) energy provision to Base Transceiver Stations and small data centers. The proposed concept is based on a high-efficiency natural gas driven SOFC-CHP coupled to commercially available thermally driven adsorption chillers. The main components of the system were experimentally characterized under relevant boundaries and the obtained performance maps were used to implement a TRNSYS model of the whole multi-generation system. The developed model was used to investigate the effect of the sizing of each component as well as the integration of two different commercial thermally driven chillers on the achievable global efficiency. This analysis demonstrated the possibility of getting global energy efficiency up to 0.63 and yearly primary energy savings up to 110 MWh. CO_2 emissions avoided are up to 43 t/y.

1. Introduction

The rapidly growth both of number of smartphones used worldwide and of technologies in telecommunication sector such as 4G and 5G has enhanced user connection demands, requesting more and more data to manage and store by the telecom operators. This growth is involving an increase in energy consumption in telecom networks and in Data Centres [1]. The need to reduce the energy bill and to mitigate the carbonization in the telecom sector is of interest by the telecom industry. On-site energy production is an option on the table that could bring several advantages if the primary energy is produced and consumed at very high efficiency rate. Fuel cells and in particular Solid Oxide Fuel Cells (SOFC), can provide energy, both electrical and thermal, at very high combined efficiency (> 80%) [2–4] and, depending on the system configurations, at flexible voltage and temperatures levels. SOFCs typically operate in the range 700–1000 °C and ceramic material is used in the Membrane Electrode Assembly (MEA) instead of metal oxides. Due to high operating temperatures, they produce high-quality heat that could be recovered from exhaust gases as well.

Compared with other CHP technologies SOFC-CHP systems achieve higher overall efficiencies also at small-scale power range [5]. In the literature, few examples of CHP and CCHP systems combining SOFCs with absorption chillers are available [6]. Yu et al. [7] investigated the fuel utilization ratio, fuel flow ratio and air inlet temperature obtained in an integrated CCHP system incorporating a solid oxide fuel cell and a double-effect water/Lithium Bromide absorption chiller achieving a total efficiency of 84%. Takezawa et al. [8] investigated the use of SOFC-Gas Turbine exhaust gas in absorption chiller in order to obtain a sufficient cooling capacity starting from about 300 °C exhaust gas. Elmer et al. [9] investigated the GHG emission of a residential SOFC micro combined heat and power system estimating emission reductions up to 56% and cost reductions of 177% compared to the base case scenario of grid electricity and a highly efficient condensing gas boiler. Despite the limited number of studies available, SOFC-CHP technology is gaining interest, for different applications (i.e. residential and power

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https://doi.org/10.1016/j.apenergy.2018.02.063
Received 31 October 2017; Received in revised form 25 January 2018; Accepted 8 February 2018

Nomenclature

c_p	specific heat, kJ/kg K
E	electric energy, kJ
LHV	Lower Heating Value, kJ/kg
$\dot{m}$	mass flow rate, kg/s
P	electric power, kW
PE	Primary Energy, kJ
PES	Primary Energy Savings, kJ
Q	thermal or primary energy, kJ
$\dot{Q}$	thermal power, kW
T	temperature, °C
t	time, s
$\dot{V}$	volumetric flow rate, NL/min
η	efficiency
ρ	density, kg/m^3

Subscripts

burn	burner
chw	chilled water
el	electric
ref	reformer
th	thermal
tot	total

Abbreviations

BTS	Base Transceiver Station
CCHP	Combined Cooling Heat and Power
CHP	Combined Heat and Power
COP	Coefficient of Performance
HT	High Temperature
LT	Low Temperature
MT	Medium Temperature
SOFC	Solid Oxide Fuel Cell

plants) [10,11] and in view of more complex systems, such as micro-grid integration [12]. However, the vast majority of the studies reported in literature involve thermodynamic or numerical modelling of either the SOFC of the entire system. For instance, Fong and Lee [13] analysed a trigeneration system for residential applications powered by a SOFC, modelling the SOFC unit by means of an empirical equation derived from datasheets. Tippawan et al. [14] carried out an energy and exergy analysis of a SOFC trigeneration system, where the model of the SOFC is based on data from literature. The same approach is followed by Ranjbar et al. [15] for the validation of an electrochemical model of a SOFC unit for cooling applications. It is hence clear that system modelling activity based on experimental data is still limited.

The present paper reports the results obtained within the framework of a European Project, called On-Site, funded by Fuel Cell and Hydrogen Joint Undertaken. A small-scale multi-generation system, based on a Solid Oxide Fuel Cell (SOFC) micro-cogenerator (μCHP) coupled to an adsorption chiller was developed for providing cooling and electric energy to a telecommunication system. The SOFC generator is combined with a $NaNiCl_2$ battery, in order to perform a peak shaving service, allowing a constant power provided by the SOFC. SOFC stacks have demonstrated up to 30,000 h durability and single cells up to 90,000 h [16] with a growth rate per year of 16% in terms of lifetime. Preliminary evaluation about viability of the system, in terms of overall energy and economic performance, when compared with alternative CHP technologies, can be found in [5,17]. Antonucci et al. [17] showed that the considered CHP system can achieve thermal and electric system efficiency values close to 80% and 8% respectively, a primary energy savings around 4000 kWh/y/kW and admissible costs around 3000 €/kW. These values are promising, if compared with values calculated for other μ-CHP technologies, such as the conventional internal combustion engine, or others e.g. micro-Rankine cycles, micro-turbines, Stirling engines and thermo-photo-voltaic systems.

This paper presents then for the first time the investigation on a small size (i.e. < 20 kW of cooling power, < 10 kW of electric power) multi-generation system for telecommunication applications. Two main novelties are introduced: the main system components, namely, a

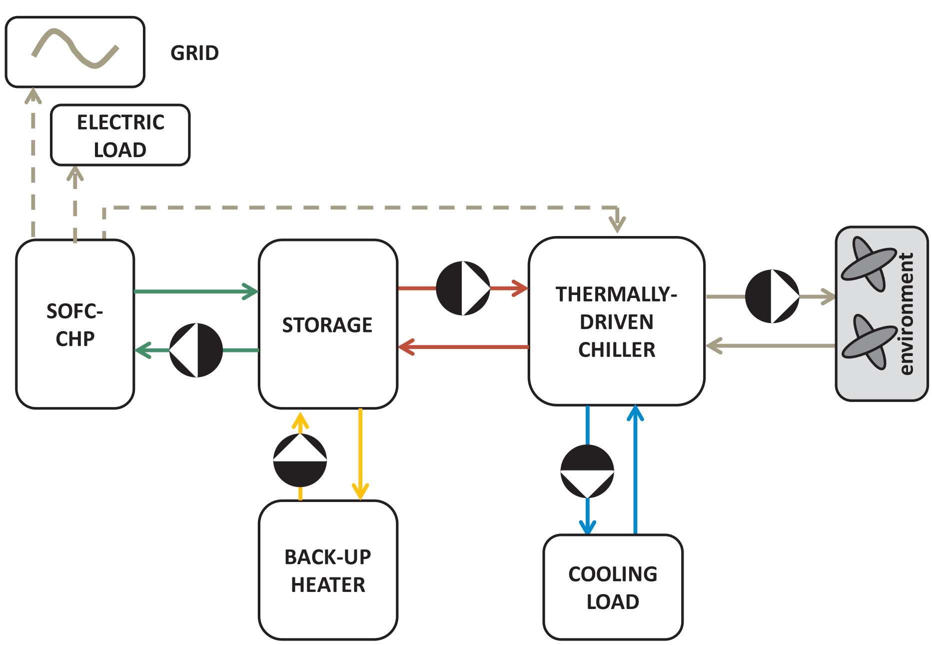

Fig. 1. Layout of the multi-generation system. Solid lines indicate hydraulic lines, dashed lines indicate electric lines.