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Polygeneration system based on PEMFC, CPVT and electrolyzer: Dynamic simulation and energetic and economic analysis

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HIGHLIGHTS

- A novel polygeneration system is presented.
- System includes CPVT collectors, PEM fuel cell, absorption chiller and electrolyzer.
- The system provides heating/cooling, domestic hot water, electricity, hydrogen and oxygen.
- The system simple payback period is 12.5 years, 5.8 years in case of incentive.
- The optimal fuel cell nominal power results 100 kW.

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ABSTRACT

This paper presents a dynamic simulation model and an energetic and economic analysis of novel polygeneration system. The system integrates: cogenerative Proton Exchange Membrane Fuel Cell (PEMFC), Concentrated PhotoVoltaic-Thermal (CPVT) collectors, alkaline electrolyzer and single-stage LiBr/H_2O absorption chiller. The plant is designed to supply electrical energy, space heating or cooling and domestic hot water for a small university building. The system produces hydrogen and oxygen, the first one is stored and then it is supplied to the fuel cell, while the second one is sold. The electrolyzer system is powered only by the CPVT collectors, only a small amount of the solar electrical energy is available to the user. Such electric energy along with the one produced by the PEM fuel cell are used by the user and/or supplied to the grid. The system is designed and dynamically simulated using TRNSYS software package. This study is based on a model previously developed by the authors. In particular, the system was modified in order to implement the new components (CPVT, alkaline electrolyzer, hydrogen and oxygen system) in this work. Special attention is paid to the control strategy of the proposed system in order to achieve the optimal system configuration. Daily, weekly and yearly results carried out with the dynamic simulation are presented. Finally, a sensitivity analysis was performed in order to determine the system performance as a function of the main design parameters. The energetic and economic analysis shows that the system can ensure significant energy savings and it can be profitable in presence of a capital investment incentive. The total energy efficiency of the CPVT collectors, calculated with respect to the beam radiation, is above 80% and the fuel cell electrical and thermal efficiencies resulted 35.0% and 43.4%, respectively. The hydrogen production of the electrolyzer system covers 4.3% of the fuel cell hydrogen demand. The Simple Pay Back period, in case of incentive, results of about 5 years when the optimal FC nominal power of 100 kW is selected.

1. Introduction

During recent years, the interest in research and development of efficient energy conversion systems has grown due to the increase of world energy demand. In this framework, polygenerative systems are particularly interesting in terms of energy supply decentralization, reduction of greenhouse gas (GHG) emissions, energy security and avoided electricity transmission and distribution networks [1]. Polygeneration technology is usually based on gas or steam turbines, nevertheless also some new technologies based on fuel cells [2,3] and renewable energy sources [4] are cur-

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Nomenclature

A	area (m^2)
a_1	Faraday efficiency parameter (mA/cm)
a_2	Faraday efficiency parameter (–)
c	specific heat (J/(kg K))
C	cost or thermal capacity (€) or (kJ/°C)
COP	coefficient of performance (–)
E	energy (kW h)
F	Faraday constant, 96,485 C/mol
f	utilization factor (–)
G	Gibbs energy (kJ/mol)
H	enthalpy (kJ/mol)
I	solar energy (kW h)
i	electric current or electric current density (A) or (A/m^2)
J	savings (€/year)
N	number (–)
n	gas production (mol/s)
P	electric power (kW)
PE	primary energy (kW h)
Q	thermal power (kW)
R	thermal resistance (°C/kW)
r_1	ohmic resistance coefficient ($\Omega\ m^2$)
r_2	ohmic resistance coefficient ($\Omega\ m^2/°C$)
S	entropy (kJ/(kg °C))
SPB	simple pay back (years)
s_1	overvoltage on electrodes parameter (V)
T	temperature (°C) or (K)
t_1	overvoltage on electrodes parameter (m^2/A)
t_2	overvoltage on electrodes parameter ($m^2\ °C/A$)
t_3	overvoltage on electrodes parameter ($m^2\ °C^2/A$)
U	voltage (V)
z	number of electrons transferred per reaction (–)

Greek symbols

Δ	variation (–)
η	efficiency (–)

Subscripts and superscripts

ACH	referred to absorption chiller
AIR	air
amb	ambient air
bottom	bottom
ca	capital subsidy
cell	referred to electrolyzer cell
CH	referred to hydrogen compressor
CHW	chilled water
CO	referred to oxygen compressor
cool	cooling
CPVT	CPVT solar collectors
CT	referred to cooling tower
CW	cooling water
density	density
DHW	domestic hot water
DW	distilled water
EL	referred to electrolyzer
el	electric
FC	referred to fuel cell
f	Faraday
H_2	hydrogen
HE	referred to HE heat exchanger
heat	heating
HS	referred to hydraulic separator
HW	hot water
GB	referred to GB gas boiler
gen	generated
in	inlet
loss	loss
NG	natural gas
nom	nominal
O_2	oxygen
out	output
P	referred to pump
PS	proposed system
PV	photovoltaic
ref	reference condition
rev	reversible cell voltage
RS	reference system
SCF	solar collector fluid
tank	tank
th	thermal
TK1	referred to TK1 tank
TK2	referred to TK2 tank
TKH	referred to TKH tank
tn	thermoneutral
top	top side
tot	total
user	referred to user hydronic system
water	water

rently under investigation. Fuel Cell (FC) technologies have been optimized in recent years due the modelling, simulation and experiments [5,6], such improvement has performed for PEM [7], Solid Oxide Fuel Cell (SOFC) [8], Molten Carbonate Fuel Cell (MCFC) [9] and microbial units [10]. Special attention has been paid to the development of novel renewable polygeneration technologies and systems [11,12]. Different system configurations and energy sources have been adopted for renewable polygeneration systems: solar thermal [13], solar photovoltaic/thermal [14], geothermal [15] and biomass [16]. However different layouts of renewable polygeneration system integrating more than one energy source have been also analyzed in the available literature, such as hybrid systems integrating solar source and biomass [17] or solar and geothermal energy sources [18].

An interesting application of polygeneration technology consists in the application of both solar and fuel cell technologies. In particular, Akikur et al. [19] presented a cogeneration system capable to deliver electrical and thermal energy using the solar energy and a Reversible Solid Oxide Fuel Cell (RSOFC). Different operation modes of parabolic trough solar collectors (PTSC), photovoltaic panels (PV) and SOFC have been considered in order to assess the system performance.

Renewable energy and fuel cell based polygeneration technologies represent a viable option for meeting the electrical and thermal demand of buildings [12,20]. Such systems have been widely investigated in literature, in several applications [21–25]. In particular, Oh et al. [21] studied a cost-effective method for integration of new and renewable energy systems in several Korean public buildings. They analyzed photovoltaic, solar thermal, wind turbine, fuel cell, electric/ground source heat pump and boiler technologies as possible energy systems in order to match the electric, cooling, heating and hot water demand of such buildings. Different results

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