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The role of hydrogen in achieving the decarbonization targets for the UK domestic sector

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ARTICLE INFO

Article history:
Received 12 November 2013
Received in revised form
3 January 2014
Accepted 7 January 2014
Available online 11 February 2014

Keywords:
Hydrogen
SOFC
Battery
PV
Demand
Modelling

ABSTRACT

To meet the UK's decarbonization targets the introduction of novel integrated renewable energy generation, storage and demand management systems is required. In this paper the current role of fuel cells in the British domestic sector is discussed using simulation results of a solid oxide fuel cell (SOFC) system in a typical British single dwelling. 17% of carbon dioxide emissions are saved and 69% of the electricity generated by the SOFC system is exported to the grid for this single dwelling according to simulation results. Additionally, the same SOFC system is integrated with photovoltaic technology in a 7 home zero carbon community. The community approach adds a significant benefit given it increases the amount of electricity generated by the SOFC system which is used onsite by 128%, being the price of imported electricity 3 times higher than the export tariff. Then, a combination of short-term and long-term energy storage strategies is suggested by means of a lithium-ion battery and polymer electrolyte membrane (PEM) electrolyser which increased the self-consumption by 118%. According to simulation results, a 6 kW PEM electrolyser with an annual efficiency of 66% only generates 19% of the hydrogen which is consumed by the SOFC system which was used to meet the peak demand using PV generation.

1. Introduction

Renewable energy penetration together with other types of distributed generation is expected to rise due to environmental concerns and other issues related to fossil fuels such as its increasing cost, uncertainty of secure supply and the expected depletion of reserves. Specifically, the UK government stated quantifiable binding objectives for 2020 and 2050 [1], aiming to reduce CO_2 emissions by 34% and 80% respectively, taking 1990 as a base reference. Many other countries are legislating similar strategies in order to adapt their economies and energy systems for renewable energy technologies.

However, the flexibility for the continuous balance of demand and generation is given by thermal generation plants (gas, coal and diesel) which offer ramping capability. Renewable energy technologies are intermittent because they depend on weather conditions [2] and they do not offer matching capability. Thus an energy system with an integral renewable energy installed capacity needs alternative technologies to match variable demand and generation.

Similarly the decarbonization of the heating and transport sectors will be necessary to achieve the above targets because

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0360-3199/$ – see front matter
http://dx.doi.org/10.1016/j.ijhydene.2014.01.023

both sectors rely on fossil fuels and accounted for 21% and 15% of the total emissions in the UK in 2010 [3]. Any new decarbonized "smart grid" should integrate new heating and transport technology at the consumption level. The use of flexible energy vectors such as hydrogen and electricity will be a key element in order to balance renewable generation and electricity, heating and transport demands.

The domestic sector is attracting a lot of attention because buildings account for 27.1% of final global energy consumption (40% including the commercial sector) [4]. The decarbonization of the heating demand is one of the challenges to arise because heating and domestic hot water (DHW) demand account for around 75% of the energy consumption in buildings [1]. Two strategies for decreasing the energy consumption in the domestic sector are the reduction of the demand requirements, by introducing improvements such as insulation, reduction of the stand-by consumption of appliances, low energy appliances and lighting (passive measures), and the penetration of micro-renewable technologies and other types of efficient distributed generation technologies (active measures).

Hydrogen is an energy vector which can play an important role in a widely distributed renewable energy scenario [5]. There is a marked interest in the introduction of hydrogen fuel cell (FC) vehicles to decarbonize the transport sector. Likewise, hydrogen can be used for domestic and commercial applications for supplying electricity and heating. FCs have some potential advantages over internal combustion and Stirling engines such as higher efficiency, quiet operation and lower emissions when performing as combined heating and power (CHP) generators [6]. However, there are still several challenges to overcome for FCs related to the durability of fuel cell stacks, cost and the balance of electricity and heat generation with the electrical and thermal load maximizing the number of operational hours in order to justify the investment [7].

Two different scenarios have been designed in order to understand the role of a solid oxide fuel cell (SOFC) system in a current single home and in a 7 zero carbon community. 7 homes were selected in order to compare simulations results with experimental work being carried out in an efficient 7 homes community at the University of Nottingham (Creative Energy Homes) which is used as a real experimental platform for researching different sustainable technologies such as renewable energy technologies and hydrogen storage [8]. All the input data required to model the zero carbon community has been taken from the 2 most plausible British government scenarios for 2050 [9]. This community can also be considered as a new development after 2016 when all new houses should zero carbon homes [1]. The SOFC system is the only common element in both scenarios but the hydrogen utilized is generated from natural gas and from renewable energies sources in the single home and zero carbon scenarios respectively. Additionally, a benchmark scenario is included to compare the carbon savings of the two alternatives with the reference situation. The most important details of the three scenarios are summarized in Table 1.

In the single home with the SOFC system, a back-up natural gas boiler was selected to supply the heat necessary to satisfy all remaining demand requirements, also utilized in many other works because it is the most widespread heating system [7,10–12]; while the national grid is also used as a buffer to import and export electricity whenever there is a mismatch between electrical generation and demand [13]. On the other hand, the SOFC system is integrated with heat pump (HP) technology and all the houses have a PV installation of 3 kW_p and solar thermal panels which supply part of the domestic hot water (DHW) demand in the zero carbon scenario. Additionally, energy storage is used to match the local generation with the demand.

2. The current approach to using CHP units in the British domestic sector

CHP units generate both electricity and heat on-site aiming at increasing the efficiency of fuel utilization and they have been considered as a complementary energy system to renewable energy technologies in a transition to a low carbon economy [7,10]. CHP installations have already been introduced for service buildings such as hospital and sport centres, where electricity and especially heating demand are more constant throughout the year [14] and in communities where the aggregation of demands increases the number of operational hours using a district heating network to supply heat. However, district heating provides approximately 1–2% of the UK's heat demand. As a consequence, most research has focused on micro-CHP units for single dwellings in the UK [10,13,15]. According to this research, although 1–3 kW_e micro-CHP units offer potential for cutting carbon dioxide emissions in single dwellings up to 16% [10], experimental results show that the final efficiency (less than 80% in most field trials as reported by Staffel) and the number of operational hours are reduced. Peacock and Newborough obtained that a 1 kW FC only run 44% of the year when following the thermal load [10] and Staffel reported that the average operational hours achieved during a field trial were 5454 per year [7]. The use of energy storage such as water tanks and batteries to balance electricity and heating generation and demand was suggested by Hawkes et al. [15] and was put into practice in a pilot project commissioned by

Table 1 – Comparison of the three scenarios discussed in this work. In the zero carbon scenario, renewable hydrogen is achieved by a combination of local renewable generation and external sources as discussed in Section 7.2.

	Benchmark scenario	Single home with SOFC system (scenario 1)	Zero carbon scenario (scenario 2)
Community size	Single home	Single home	7 home community
Electricity supply	Import	SOFC system and import	SOFC system, PV energy and energy storage
Heat supply	NG boiler	SOFC system and NG boiler	SOFC system, HP and solar thermal energy for DHW
Hydrogen generation	None	Natural gas	Renewable energy