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Applied Energy xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Technical and economic analysis of hydrogen refuelling

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HIGHLIGHTS

- Technical and economic models of a hydrogen station for vehicles refuelling.
- Hydrogen demand from fuel cell electric vehicles modelled stochastically.
- Study case based on a UK pilot project.
- Operation of the H_2 station using combined energy from wind and power grid is preferred.
- Return on investment of 5–10 years is possible for the hydrogen station.

ARTICLE INFO

Article history:
Received 28 June 2015
Received in revised form 29 September 2015
Accepted 13 October 2015
Available online xxxx

Keywords:
Hydrogen production
Hydrogen economics
PEM
Alkaline
Wind integration

ABSTRACT

This paper focuses on technical and economic analysis of a hydrogen refilling station to provide operational insight through tight coupling of technical models of physical processes and economic models. This allows the dynamic relationships of the system to be captured and analysed to provide short/medium term analytical capability to support system design, planning, and financing. The modelling developed here highlights the need to closely link technical and economic models for technology led projects where technical capability and commercial feasibility are important. The results show that hydrogen fuel can be competitive with petrol on a GBP/KG basis if the return on investment period is over 10 years for PEM electrolysers and 5 for Alkaline electrolysers. We also show that subsidies on capital costs (as reflected by some R&D funding programs) make both PEM and Alkaline technologies cheaper than the equivalent price of petrol, which suggests more emphasis should be put on commercialising R&D funded projects as they have commercial advantages. The paper also shows that a combined wind and grid connected station is preferable so that a higher number of customers are served (i.e. minimum shortage of hydrogen).

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1. Introduction

Global pressure is continuing to drive methods to reduce our carbon emissions throughout the energy supply chain, from raw fuels to products. The level of reductions required points to a shift in energy sources as well as social habits. This is likely to require a mix of different technologies which may differ between countries based on local needs, context, and resources. Amongst potential technologies, hydrogen is gaining prominence as a crucial part of a low carbon future for a number of countries. A study found that there were 224 working hydrogen stations over 28 countries in 2013 [1]; notably 43% were located in North America and 34% in Europe [1]. In recent years Japan has promoted hydrogen fuel cells as a way to de-risk their energy supply chain as well as creating reserve energy in cases of emergency. A review of UK hydrogen related activity [2] shows the appetite for hydrogen related research and commercialisation with activities ranging from fuel cell technology to socio-economic issues. The paper [2] highlights the need for a collaborative approach into this area in order to realise the commercialisation of hydrogen and fuel cell systems. Taking such technology into commercial operation in a transport context is complicated further as it requires new infrastructure and technology to be adopted in a coordinated fashion [3] leading to the proverbial 'chicken and egg' situation.

As a reflection of the development of technology and potential of hydrogen, the European Commission set up the Fuel Cell and Hydrogen Joint Undertaking (FCH JU)[1] in 2008 and renewed the

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[1] http://www.fch.europa.eu/.

http://dx.doi.org/10.1016/j.apenergy.2015.10.094
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Please cite this article in press as: Nistor S et al. Technical and economic analysis of hydrogen refuelling. Appl Energy (2015), http://dx.doi.org/10.1016/j.apenergy.2015.10.094

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initiative in 2014. The nature of projects suggest that the commercialisation of hydrogen and fuel cell systems are expected to be realised.

This paper aims to explore and analyse the short to medium term feasibility of hydrogen refuelling with onsite hydrogen generation using a pilot project (Island Hydrogen) in the UK as a use case. In particular we analyse the performance (unit cost of hydrogen) current state of hydrogen refueller technology (both PEM and Alkaline electrolysers) in order to address the present case for hydrogen fuelled transport without relying on reductions in future technology costs. We then evaluate the effectiveness of a refuelling site in terms of serving customers based on primary energy source (wind power versus grid power). Finally, we evaluate the commercial impact of R&D funding on the system to reflect the efforts of national policies which direct funding towards such trials (e.g. in the European Union).

The paper is organised as follows; Section 2 covers relevant work in the literature, Section 3 provides system and simulation details, Section 4 presents Island Hydrogen as a case study and discusses results, and finally Section 5 makes some conclusions and highlights areas for further work.

2. Relevant work

This paper looks at technical and economic analysis of a pilot project in order to evaluate feasibility of the system to satisfy demand and to be economically attractive. A study [4] investigate realistic cost estimates coupled with confidence in the technical performance of hydrogen Fuel Celled Electric Vehicles (H2 FCEV). The need for government commitment and coordination amongst stakeholders is also highlighted to help create momentum for the sector. In a Californian based study [4], an approach of clustering refueler stations was explored and found to be a better strategy than simply allocating refuelers in proportion to population density. The authors also noted [4] that subsidies and government policy directed at alleviating the high capital cost and long payback period would assist in encouraging private investment and technology adoption.

Previous techno-economic analysis of hydrogen production for FCEV's has found that the price of electricity is the key driver in cost [5]. The study [5] also found that in addition to electricity costs, key factors with medium to high impact are; storage, compression, volume produced, size, financing, capacity factor and electrolyser efficiency. The work [5] is limited in the depth to which the technical aspects are modelled with the authors noting that a number of couplings are not reflected explicitly in the model. The model [5] assumes that the electrolyser functions at nominal production capacity which in practice is unlikely to happen.

A more recent study [6] has looked at a self-sustaining hydrogen fuelling station where the power to operate the electrolyser is purely from renewable sources. They find that using power from the generation sources to directly run the electrolyser is preferred to using a fuel cell to balance the intermittency. They found that 200 kW wind turbines or 360 kW solar PV could successfully operate in a self-sustaining manner while producing approximately 25 kg of hydrogen [7].

Modelling hydrogen vehicles and refuelling infrastructure using the lens of complementary goods [8] suggests that favourable market conditions are required for FCEV's to penetrate the market. The study analysed four scenarios using system dynamics where the most successful scenario required both investment in infrastructure and fuel subsidies [8]. However, this type of longer term analysis can be very difficult given the high uncertainty of a number of factors such as component life time, manufacturing costs, and maintenance costs [9].

These papers highlight a key issue in the hydrogen refueler domain which is the close linkage between economic and technical factors and the impact on the overall competitiveness of such schemes. There are a number of simulation environments that have started to integrate technical and economic models with which one can analyse energy systems more generally. The Department of Energy in the USA have created the hydrogen analysis (H2A) tool[2] which allows analysis of the economics of hydrogen production systems as well as some technical attributes related to this (mainly the electrolyser). The analysis is well suited towards medium-long term system analysis however doesn't allow for detailed technical models and real-time analysis. The National Renewable Energy Labs developed and have now commercialised HOMER [10], a microgrid simulation tool. HOMER also contains hydrogen related components (electrolyser and storage) and has simulation granularity of 1 min to 1 h. The system is proprietary hence customising scenarios and technology performance can be difficult. In the realm of real-time simulation systems, TRNSYS [11] provides real-time analysis capability for technical systems which is suitable for analysing short term scenarios. A study in [12] investigated the use of wind power to produce hydrogen for the public and private transport sectors. The authors used TRNSYS to obtain the optimal sizing of the equipment and further used HOMER to obtain the economic results. The study found that given a wind penetration higher than 60%, the price of hydrogen is comparable with the price of fuel. A constant hydrogen demand for the transport system has been considered in this study. In contrast, our study captures the daily pattern of refuelling that influence the operation of the station and the economic results. Moreover, we also explored the economics of operating the station with renewable and grid electricity.

The key limitations we find in the available simulation environments is that they are either mainly economic models with limited technical features or detailed technical models with little or no economic and policy views. Hence, the work presented here is based on a customised simulation environment where detailed technical models of the physical processes (e.g. electrolysis, compressors, buffer, and dispenser) are coupled with economic models from the literature. The granularity of the simulation allows for dynamic effects of the system (e.g. generation) to be captured, giving a more realistic representation.

A system model capable of representing the dynamic operation of a wind-hydrogen system for the purpose of power balancing is described in [13]. Models of the electrolysers, fuel cell, converter, electrical load and wind turbine are given. In [14] a residential photovoltaic-hydrogen system is introduced. Compared with the previous paper, models of the PV, battery and a supercapacitor are also added. The systems presented in [13,14] are developed in Matlab/Simulink software to study the stand-alone operation of hybrid renewable-hydrogen systems. They are suited to test control strategies for balancing of power with a timespan of seconds or short-term energy balancing with a timespan of days. Extended timespans are constrained by the duration to complete the simulation [13]. The hydrogen refuelling system we introduce in this paper is grid connected, therefore the power balancing was not the focus. As a result, a coarser resolution of the simulation can be selected which allows to perform studies with timespans of years, suitable to understand the system economics.

Other research which investigated power-to-grid cases [15–17] which we note as being of relevance and indeed being trialled in Germany [15]. A paper [18] which looked at both utilisation of the hydrogen from renewable energy, power-to-fuel and power-to-grid deemed the first option as the most commercial viable.

[2] http://www.hydrogen.energy.gov/h2a_analysis.html.

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