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Optimal operation of a hydrogen refuelling station combined with wind power in the electricity market

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ABSTRACT

An optimisation routine has been developed to analyse the performance of hydrogen refuelling stations combined with wind power operating in electricity markets. This optimisation routine includes the minimum turn down ratio of the electrolyser in its formulation resulting in a mixed integer nonlinear programming optimisation. The optimisation routine has been used to analyse the performance of a hydrogen refuelling station located at the advanced manufacturing park in Rotherham, UK. The performance of the optimisation routine for various scenarios of hydrogen demand and wind power has been assessed. This includes the effect of operating the electrolyser to reduce wind curtailment in a grid constrained scenario. It is found that the optimisation routine is capable of increasing profits when operating in the market, but this is dependent on various factors such as the level of hydrogen demand and wind power.

Introduction

With increasing concerns over energy security and anthropogenic climate change [1], new methods of generating and utilising energy must be developed. Hydrogen has the potential to aid in increasing the use of renewables and reducing greenhouse gas emissions by acting as an energy carrier and storage medium [2]. Increasing the use of alternative fuels in the transportation sector is vital to reduce greenhouse gas emissions, with hydrogen fuel cell electric vehicle (HFCEV) and battery electric vehicles (BEV) both having the potential to achieve this [3]. HFCEVs are increasingly becoming commercially available. In order to support the deployment of hydrogen vehicles, it is important to develop a refuelling network, and to assess the performance and operation of refuelling stations. BEVs are at a more advanced stage in their deployment, and the benefits of using BEVs for demand management has been investigated by a number of researchers. Druitt and Früh investigated the use of BEVs to provide demand management to the UK system assuming high wind penetration, finding that this method could aid in integrating wind power as well as allowing vehicle owners to derive revenue from operating in the electricity market [4]. Boait et al. investigate the use of BEVs as part of a domestic demand side response method in

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the UK [5] whilst Sortomme and El-Sharkawi determine the performance of different charging algorithms for BEVs operating in an electricity market [6]. To take part in demand side management and balancing actions, BEVs must be somehow attached to the electricity network. This makes them dependent on suitable infrastructure, limits the times at which they can take part in balancing and market operation, and is dependent on the local network to which they are connected allowing power flows at appropriate times. Hydrogen energy storage can be used as a means of helping to integrate renewables on to the electricity network, with both round trip storage [7] and demand from HFCEVs [8] having the ability to increase renewable penetration on constrained networks. Hydrogen can aid in implementation of smart energy networks by providing an energy storage and distribution vector [9].

HFCEVs are likely to be refuelled in a manner similar to conventional vehicles. The shorter refuelling time for HFCEVs compared to battery electric vehicles means that hydrogen refuelling infrastructure is likely to consist of hydrogen refuelling stations, where drivers of HFCEV's can refuel in a similar manner to conventional vehicles. In the UK, development of a hydrogen refuelling infrastructure is being investigated [10]. One possible method of providing hydrogen to forecourt refuellers could be on-site electrolysers with hydrogen storage facilities. These electrolysers will have the ability to generate hydrogen independently of refuelling demand, which could help facilitate their operation in electricity markets.

A number of different aspects relating to hydrogen refuelling stations have previously been investigated. Those studies focussing on operation of the station without considering hydrogen generation have investigated hydrogen storage tank sizing, configuration and control strategies [11] minimizing energy use due to compression through cascaded storage tanks [12,13] and minimizing refuelling time [14]. Oi and Sakaki [15] looked at the optimal sizing of electrolysers in hydrogen refuelling stations operating off-peak, but did not investigate the electrolyser operation. Dagdougui et al. [16] determine the optimal performance of a network of hydrogen refuelling stations powered by renewable electricity based on population density and renewable supply. The ability of electrolysers to replace spinning reserve in a high wind penetration UK scenario was investigated by Kiaee et al. [17], but they did not investigate factors such as hydrogen demand and control strategies. Other investigations have provided feasibility studies of renewable hydrogen stations [18,19] including residential refuelling stations [20], determined the impact of environmental conditions on refuelling station operation [21], and analysed the optimal performance conditions for renewably power refuelling stations [22].

A small number of electrolytic hydrogen refuelling stations are now operational in various countries. For example, Kiaee et al. [23] report on a hydrogen refuelling station located in Norway. The hydrogen is produced by a pressurised alkaline electrolyser and various scenarios are investigated including being powered by renewable energy. Whilst detailed performance is characterised, operational detail such as investigating the electrolyser scheduling and vehicles refuelled is not reported.

As stated previously, a major advantage of electrolytic hydrogen refuelling stations is that they can separate refuelling demand from electrolyser operation. By doing this they can aid in integrating renewable electricity, and can take advantage of operating in the electricity market. Korpas et al. [24] investigate using hydrogen storage in an electricity market, including a hydrogen demand from a single bus in their simulation. The paper demonstrates the ability of hydrogen storage to increase profits in market operation, but focusses primarily on round trip storage. When considering the minimum electrolyser power, they do not include it fully in the optimisation routine, which could lead to sub-optimal results. In Ref. [25] Korpas et al. consider a similar system operation with a grid constrained electricity import/export capacity, but do not consider market operation. Xiao et al. [26] report on the performance of a hydrogen filling station operating in the electricity market, finding that the cost of hydrogen can be reduced by this method, but they do not consider the possibility of operating in a constrained grid, or the operational constraints of the electrolyser such as a minimum power input.

In this paper an analysis of a hydrogen refuelling station based at the advanced manufacturing park (AMP) in Rotherham, UK is presented. The effect of operation in the electricity market is determined, as well as the number of cars which the station can refuel and how this affects operation in the electricity market. The minimum operating power of the electrolyser is modelled by including an on-off variable in the optimisation, resulting in a mixed integer non-linear programming optimisation problem. This allows the performance of different electrolyser technologies to be compared. The ability of the refuelling station to operate with wind power in a grid constrained scenario, and the effect of this on performance is also investigated.

Description of refuelling station and parameters

Refuelling station at the advanced manufacturing park, Rotherham

The Island Hydrogen project [27] aims to deploy and investigate the performance of hydrogen refuelling stations in the UK. As part of this, a hydrogen refuelling station has been developed by ITM power at the AMP in Rotherham. The site was already the location for a 225 kW wind turbine. The refuelling station, wind turbine and an office building are all connected to the local electricity network via the same substation as represented in Fig. 1. The network is sometimes constrained so that the electrolyser is not always able to operate at 100% power.

The electrolyser is a recently installed PEM type electrolyser with a power rating of 270 kW. The electrolyser consumes 52 kWh/kg hydrogen produced, equivalent to 76% electrolyser efficiency based on hydrogen HHV. After production, the hydrogen is compressed before it is stored at a maximum pressure of 350 bar. The combined compressor and dispenser unit consumes 10.2 kWh/kg of hydrogen with a peak power consumption of 45 kW. This gives a total efficiency of 63%, with a peak power of 315 kW. When operating,

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