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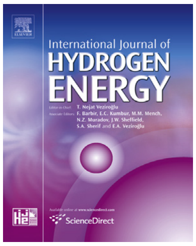

Hydrogen storage and demand to increase wind power onto electricity distribution networks

Stephen Carr[*], *Giuliano C. Premier*, *Alan J. Guwy*, *Richard M. Dinsdale*, *Jon Maddy*

Sustainable Environment Research Centre (SERC), Faculty of Computing, Science, and Engineering,
University of South Wales, Pontypridd, Mid-Glamorgan CF37 1DL, United Kingdom

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ABSTRACT

An optimal power flow (OPF) methodology is developed to investigate the provision of a demand hydrogen as a means to maximise wind power generation in relation to a constrained electricity network. The use of excess wind energy to generate hydrogen for use as a transport fuel is investigated. Hydrogen demand is included in the objective function of the OPF, and a techno-economic analysis is presented. We conclude that using this method to generate hydrogen increases the utilisation of wind energy and allows for a hydrogen demand to be met at or near to the point of use. The OPF algorithm that has been developed optimises the amount of wind energy utilised, as well as minimising the amount of hydrogen demand not met. The cost at which the hydrogen is produced was found to be dependent on the operating methodology, component capital investment costs, level of hydrogen demand, and storage constraint.

Introduction

Renewable energy from intermittent and variable sources such as wind, wave and solar is expected to make an increasing contribution to worldwide energy supplies in the near future [1]. For example, the UK is committed to supplying 15% of its energy demand from renewable sources by 2020, in line with a long term goal to reduce carbon emissions by 80% by 2050 [2]. With increasing penetration of renewable energy, new methodologies in the way we manage our energy supplies are required. In particular, connection of an increasing amount of intermittent renewable energy to electricity networks can cause a number of problems with the operation of those networks. New methods are required by which to manage and operate these networks to ensure their safe operation with optimal utilisation of the renewable resource smart [3]. Energy storage and closer integration between different energy vectors can help in integrating renewables [4]. Hydrogen has the potential to play a major role as part of our future energy system as it is energy dense by weight and can be produced from a number of primary sources, but importantly because it can be used transferably as a store for intermittent renewable energy and as an energy carrier/fuel for vehicles [5].

The power level and location of renewable electricity sources often make them most suitable for connection to electricity distribution networks. The problems associated

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[*] *Corresponding author*. Tel./fax: +44 1639 816426.
E-mail addresses: sjwcarr@gmail.com, stephen.carr@southwales.ac.uk (S. Carr), iano.premier@southwales.ac.uk (G.C. Premier), alan.guwy@southwales.ac.uk (A.J. Guwy), richard.dinsdale@southwales.ac.uk (R.M. Dinsdale), jon.maddy@southwales.ac.uk (J. Maddy).

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with connecting renewable generation to electricity distribution networks serve to limit the amount of generation that can be connected to the network, and can result in underutilisation of viable renewable energy resources [6]. Generation capacity on the network is typically allocated on a worst case scenario basis, typically at maximum generation and minimum load, in order to allow the network to be operated in a passive way. This means that no control actions are required to accommodate the generator, for all combinations of generator outputs and loads on the networks. A renewable resource such as wind power tends to operate below its maximum output during large periods of its operation, with the worst case scenario only applicable for a very small portion of time. An active method of managing the network would allow greater generation capacity to be connected to the network than with passive control, so allowing fuller utilisation of the renewable resource. Active management techniques include reactive power control, on load tap changing (OLTC) transformer control, energy curtailment, load control and energy storage [6]. Energy storage has advantages as a potential solution to this problem, in that it can shift the time of use of the energy generated by intermittent renewable energy sources such as wind power. The use of hydrogen for energy storage not only allows for the time of use to be shifted, but also for the energy stored to be used for purposes other than supplying electricity demand, i.e. in a hydrogen economy [7]. One of the main potential uses of hydrogen in a hydrogen economy is as a vehicle fuel [8]. The interaction of electricity and hydrogen as energy carriers is of interest due to their complementary characteristics [9].

Previous work on integrating renewable energy onto electricity networks has focussed on aspects such as curtailment of wind power or adjustment of network parameters [6], whilst more recently some attention has been paid to utilising energy storage [10]. This reflects the idea of using smart grids and active network management to integrate more renewable energy onto electricity networks [4]. Where hydrogen has been considered the electricity network has only been included in a simplified form [11]. The concept of using vehicles as an energy store for renewable electricity, and as a means of grid balancing has attracted significant attention, mostly considering electric vehicles for energy storage [12]. Hydrogen has advantages over electricity in that can be a more economical means of long term storage and can be more suitable for larger vehicles [8], or allow vehicles a greater range. This suggests that the use of hydrogen vehicles as a grid balancing tool to aid in integrating renewable energy should be investigated. Where hydrogen vehicles have been considered, such as using hydrogen as a vehicle fuel to reduce network management costs in high wind penetration scenarios [13] or to realise the benefits of utilising off peak grid electricity to generate hydrogen for vehicle fuel [14], detailed analysis of the operation of an associated network has not been carried out. Other studies have focused on a country wide analysis of the transition to a hydrogen economy [15]. Component sizing and operation of wind power plants with electrolytic hydrogen production connected to electricity distribution networks has been investigated, but without considering the effect on the network [16]. Studies have also investigated generating hydrogen to balance the grid on a nationwide scale, with the hydrogen produced being used for reconversion back to electricity, or to supply a vehicle demand [17], but again without detailed consideration on the operation of the network. The optimal operation of electricity networks is an important consideration to make the most use of renewable resources.

The paper considers a novel formulation of the optimal power flow technique to consider the management of the network to optimally utilise a renewable resource whilst meeting a hydrogen demand. The paper builds substantially on work presented at the 2012 ICREPQ conference [18]. The operation of hydrogen storage in the context of a transport fuel hydrogen demand is considered by developing an objective function in an OPF which considers the interplay between them, whilst ensuring all network parameters remain within limits. This generated hydrogen is then used to supply a hydrogen demand from vehicles. A case study involving an electricity distribution network located in south Wales is used to demonstrate the OPF routine. Different methods of operating the network have been explored in order to determine and compare the proportion of wind power that is utilised, the proportion of hydrogen demand that can be supplied, as well as the cost at which the wind power and hydrogen is produced. Through this, we determine their effectiveness in aiding the integration of wind energy onto a distribution network, along with the level and cost at which the hydrogen demand can be met. A number of scenarios are investigated to determine the optimal method of operating and utilising the hydrogen storage. A financial analysis is then carried out to determine the cost at which the hydrogen can be produced.

Problem formulation

A case study involving a distribution network located in South Wales is used in this paper. South Wales has an established hydrogen industry, and has been designated as a Low Carbon Economic Area (LCEA) for hydrogen energy by the UK government [19]. The network is located in an area with good wind resources, and already has a 10 MW wind farm attached to it. The system is analysed by running an OPF algorithm considering half hourly time steps in relation to wind generation and hydrogen production, storage and demand over the course of a year. Wind farms are sized at three capacity levels, as described in section Network studied. At the smallest capacity level, the wind power output can always be accepted on to the network at each time step. At the higher capacity levels, the wind full wind power output can not always be accepted, and the OPF routine determines how much wind power is accepted onto the network, how much wind power is curtailed and how much hydrogen is produced at each time step. Time series for wind power output and electrical load are obtained from the Sustainable Electricity and Distributed Generation group [20], whilst the creation of a hydrogen demand time series is described below. The effect of different operating methodologies, storage locations and wind farm sizes on the performance and economics of the network is then determined. The hydrogen demand is based on vehicle fuel demand, adjusted to take into account the increased efficiency of a hydrogen fuel cell drive train over an ICE drive train.