

## INFLUENCES OF A HYDROGEN ELECTROLYSER DEMAND ON DISTRIBUTION NETWORK UNDER DIFFERENT OPERATIONAL CONSTRAINTS AND ELECTRICITY PRICING SCENARIOS

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### ABSTRACT

*With the long term goal of greenhouse gases reduction by at least 80% set by the UK government, and 100% renewable penetration aimed in Scotland by 2020, water electrolyser and hydrogen fuel cell vehicles provide the potential to contribute to the goals through increasing penetration of renewables in and reducing the CO<sub>2</sub> emissions in road transportation. The project on Impact of Electrolysers on the Distribution Network carried out by SSEPD secured innovation funding with an aim to investigate the potential impact of this type of technology on the electrical network. In this project, electrolyser needs to supply sufficient amount of H<sub>2</sub> to provide for 10 fuel cell buses running daily in Aberdeen urban area. A number of trials looking at various commercial arrangements and technical requirements are designed to test potential ability of electrolysers to operate under different pricing strategies or schemes designed to help integration of renewable resources.*

### INTRODUCTION

The UK government set a goal of reducing greenhouse gas emissions by at least 80% by 2050, and the Scottish government has introduced a target to generate the equivalent of 100% of Scotland's own electricity demand from renewable resources by [1][2]. A significant contribution to the goal of reducing emissions can come from increasing renewable penetration in energy sectors, as well as decarbonizing the road transportation. Typically, Electric Vehicles (EV) are regarded as an important part of sustainable future, and Fuel Cell Electric Vehicles (FCEVs), can be an alternative to EVs powered by batteries. In comparison to traditional vehicles powered by diesel/petrol, FCEVs have significantly lower carbon dioxide emissions. The UK government study presented in UK H2Mobility report [3], estimated that there would be 1.6 million FCEVs powered by hydrogen by 2030. This will require development of a supporting Hydrogen Refuelling Network that will grow with the number of vehicles, but also will need to ensure both local and GB-wide coverage. It is estimated that 1,150 fuelling station will be required to achieve this goal by 2030.

The Hydrogen for transport summary report [4] proposed a number of ways to generate hydrogen, including large central water electrolyser, small distributed water electrolyser and central SMR (steam methane reforming). As summarized in Figure 1, contribution of each of hydrogen generation methods vary under different deployment scenarios. It indicates expectation that distributed water electrolyser, which is used in this pilot project, can have a significant share of hydrogen production from 2010 till 2050 and, thus, it is reasonable to expect roll out of the distributed electrolyser in the near future.

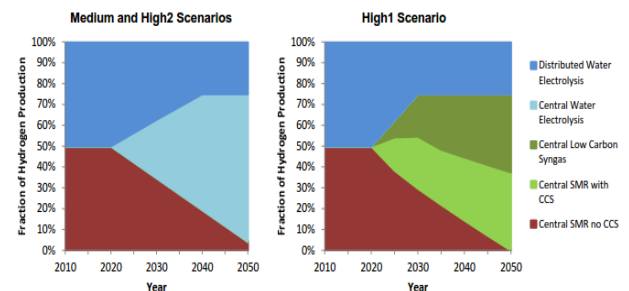


Figure 1. Hydrogen production mix scenarios [4]

However, production of H<sub>2</sub> can have a significant effect on distribution network as growing number of electrolysers can bring significant increase in electricity consumption. Thus, there is a need to manage their consumption and find incentives to coordinate their operation so to avoid adding significant load, especially during peak hours. In addition, production of hydrogen is often regarded as a flexible load since H<sub>2</sub> can be stored in tanks and used when needed. Because of that electrolysers can also help with integration of renewables. In both cases, such coordination may help postpone network reinforcement and thus reduce network investment costs.

In addition, hydrogen electrolysers are regarded as a flexible demand that has an ability to participate in provision of certain ancillary services in electricity markets, which will allow them to obtain additional revenue streams. Participation in provision of these services may affect patterns of electrolysers' demand and, therefore, have an impact on distribution network

operation. It is important to note that under current regulatory arrangements Distribution Network Operators (DNOs) are not in a position to significantly affect behaviour of electrolysers, as it is determined by their owners and commercial arrangements with suppliers and/or aggregators (in the case of participating in ancillary services). Nevertheless, it is important for DNOs to understand effects that such customers can have on their networks, especially if a significant number of hydrogen filling stations, as predicted by UK H2Mobility report [3] materialise.

With rich renewable energy resources in Scotland, the water electrolyser can be seen as a good way to utilize these resources and supply hydrogen to FCEVs. In order to evaluate effects of penetration of FCEV on the distribution network, SSEPD has undertaken a study of the impact of electrolysers on the distribution network, largely funded by the Low Carbon Network Fund (LCNF) Tier 1; this project was undertaken as part of the larger Aberdeen Hydrogen Project (AHP). Drawing on learnings from earlier projects (REF IFI) concerning the potential growth in hydrogen refuelling stations in the UK, this project considered options to support the use of electrolyser as a network service, as it would be necessary to understand how electrolysers could be controlled and integrated with renewable generation in a constrained electrical network.

As part of the AHP, a plant consisting of three electrolysers, two compressors, H<sub>2</sub> storage and dispensing units owned by BOC, supplies 10 hydrogen fuel cell electric buses operational in an inter-urban environment and is used to simulate different running profiles to support both network services and integration with wind and solar power.

## OPERATIONAL TRIALS

To evaluate effects of various operational constraints and possible commercial arrangements on distribution network, SSE developed 12 trials that were tested during the 8-months period. The aim was to investigate what a DNO can expect if the roll-out of this technology becomes more widespread, and what are the planning and operational issues that it may face.

### Overview of trials

The optimized scheduling of the electrolyser is run under different predetermined operational scenarios, for which appropriate objective function, as well as one or more of network or operational constraints are defined. Table 1 summarizes the objectives and constraints involved in the 12 trials. Two major types of objective functions are considered: (i) those that minimize cost of operating electrolyser, and (ii) those that maximize

utilization of renewable energy. Time of Use (ToU) energy pricing scheme is applied in several trials when the objective considers operational cost. As for constraints, as indicated in Table 1, they include network thermal capacity limitations, following renewable generation, hydrogen demand, etc. Depending on the trial, network capacity, real-time data from a local demand, a gas injection supply point, historic wind farm as well as PV farm data are used as inputs into scheduling.

Within each of the trials, anticipated operation of the electrolyser, which follows different objectives and satisfies specified conditions, is given via calculations of set points. These calculations are carried out by a commercial Smarter Grid Solutions software module which then sends a control signal to the system (which comprises three electrolysers, two compressors, and associated balance-of-plant). Moreover, electrolyser is connected to the hydrogen tank storage which has maximum and minimum levels of stored H<sub>2</sub>. These storage tanks are used for bus refuelling, and levels of stored H<sub>2</sub> is monitored during the scheduling process in order to ensure the hydrogen supply is adequate i.e. that it is within the minimum and maximum levels. Monitoring of current hydrogen levels is used by the scheduling tool to evaluate if the proposed set-points will be able to achieve predefined H<sub>2</sub> levels at the end of the trial. If this cannot be achieved, the control system overrides the trial objectives and operates the electrolyser to produce hydrogen at a sufficiently high rate to meet H<sub>2</sub> demand. In addition, there is a lower limit of electrolyser operating power level, below which the electrolyser may cycle due to low energy supply; this can be avoided through use of a baseload setting.

### Summary of Results

As discussed above, during each of the trials the electrolyser is operated under pre-defined operational scenarios, so to investigate its influence on distribution network under different scenarios defined by commercial arrangements and technical/operational constraints. These scenarios include running electrolyser to satisfy network condition limitations, to achieve economical operation, and to use alternative energy resources to generate H<sub>2</sub>.

The constrained local network considers limits of power capacity available to the electrolyser in order to minimize its additional impact on the grid, particularly during peak load periods. For the trials optimising economical operation, different energy price rates are used for different times of the day to reflect system demand and network availability. These are trials A-D indicated in Table 1. A number of operational scenarios test the ability of hydrogen electrolyser to help in the

integration of renewables by attempting to follow outputs of wind or PV generation and these are trials E-J.

In this paper, typical results for two trials, D which seeks to minimize costs, and F, which follows renewable generation, are discussed.

Table 1. Summary of objectives and constraints for 12 trials

Trials	Objectives		Constraints						
	Minimize Cost	Increase Renewable Penetration	Hydrogen Demand	Network Limits	Energy Pricing	Local Demand	Follow Gas	Base load	Wind /PV
Trial A	✓		✓	✓	✓	✓			
Trial B	✓		✓		✓				
Trial C	✓		✓		✓		✓		
Trial D	✓		✓	✓	✓	✓			
Trial E/K		✓	✓					✓	✓
Trial F/L		✓	✓	✓				✓	✓
Trial G		✓	✓					✓	✓
Trial H		✓	✓						✓
Trial I		✓	✓						✓
Trial J		✓	✓						✓

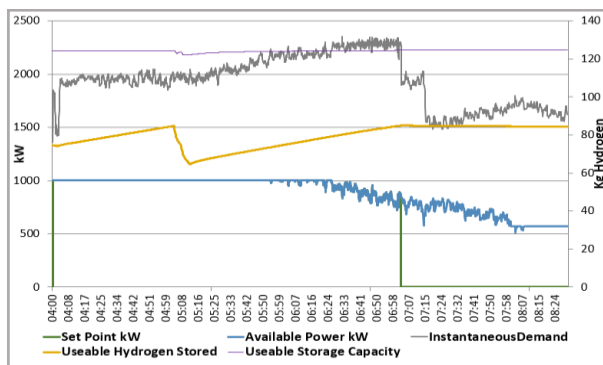


Figure 2. Example Scheduling Result for Trial D

An example of Trial D is shown in Figure 2. This trial considers minimizing the cost of running the electrolyser considering ToU tariff. In addition, the trial is for the constrained local network, where one of the constraints indicates that the sum of hourly maximum local demand and electrolyser consumption has to remain within network capacity. Figure 2 shows scheduling results for one of the D trials. Suggested hydrogen generation activities of the electrolyser can be observed through the set points, which are determined by the scheduler which instructs the electrolyser when to operate. Note that the available power to the electrolyser (blue line) in Figure 2 is decreasing over time (from off peak to peak period). Set points in this trial (green line) follow the available power, and the electrolyser respects the suggested schedule and generates H<sub>2</sub> during proposed times.

The generation activity of electrolyser can be observed through the rising amount of hydrogen stored in the storage tank (yellow line), until it reaches the predefined final value of 80kg (which is the final value defined for

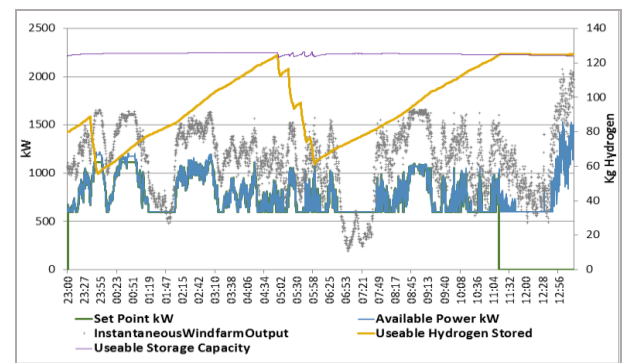


Figure 3. Example Scheduling Result for Trial F

this instance of trial). The electrolyser generates hydrogen from 4am to 7am, and achieves its goal to utilize the off peak time period to minimize operational while respecting network capacity constraint.

Objective of trial F, shown in Figure 3, is to utilize the 'spill' wind power to generate H<sub>2</sub>, while respecting a capacity limitation in the local network. The amount of 'spill' wind energy available to the electrolyser is the energy that would have to be curtailed as it exceeds the local network capacity. If electrolyser uses this energy to produce hydrogen, then the level of curtailment would be reduced. It can be noticed in Figure 3, that electrolyser effectively follows and uses available 'spill' wind power and succeeds to reach the predefined final value of H<sub>2</sub> level in the tank (123kg), while also fuelling buses during the trial period.

As mentioned above, baseload level is configured to prevent cycling of electrolyser and in this instance is set to 600 kW. It can be seen in Figure 3 that this baseload

constraint has been activated (and respected) few times during the trial period, when the wind "spill" falls below that level and electrolyser consumption is flat. The overall power consumed by the electrolyser is within the local generation limitations.

In the above described trials, the first priority is to satisfy demand for H<sub>2</sub> that is used by 10 buses running daily. Thus, the target levels which need to be satisfied at the end of each trial are set to achieve this.

Results of the trials indicated that the electrolysers can respond to the control signal within less than 2-3 minutes (and often faster). For the trials which considered network capacity limit, the sum of local demand and electrolyser load were successfully maintained at all times. Moreover, for trials which have considered economical operation of electrolyser, ToU pricing tariff has been followed, while the results of trials where electrolysers aimed to maximize utilization of alternative energy resources showed the potential of their utilization to help integration of renewable generation.

However, some instances of trials linked to renewables experienced relatively low wind/PV supply that caused the electrolyser to cycle, or to replace renewable supply with the conventional, if allowed to do so. For example, when the electrolyser demand was high during the peak time and the wind supply was too low to supply the H<sub>2</sub> demand, the electrolyser was forced to use conventional electricity during peak load period. As a result, for all the trials associated with renewable resources, the available wind/PV power needs to be adequate for scheduling the electrolyser under flexible conditions. One of the ways to improve utilization of renewable generation by electrolysers is to forecast availability of these resources as well as H<sub>2</sub> demand, and also evaluate the optimal size of storage tanks.

## **BENEFITS TO VARIOUS STAKEHOLDERS**

With adequate planning, electrolysers have the ability to act as flexible demand side response resource which can be incentivised (or controlled, depending on the arrangements) to operate during different time periods. Due to their flexibility, electrolysers can be used to offset renewable generation curtailment, and in some instances postpone network investment despite their larger consumption. Appropriate commercial arrangements and pricing schemes can lessen the effect that these larger consumers can have on network, in areas where this proves to be cost beneficial through deferred network reinforcement, provision of ancillary services, or an increase in utilisation of available renewable energy.

In addition, electrolyser can respond and change its consumption sufficiently fast to participate in the provision of balancing/ancillary services [5]. Participation in these ancillary services markets can help owners of hydrogen filling station obtain additional revenue streams and improve financial aspects of operating these installations.

## **CONCLUSIONS**

The results of successfully conducted trials prove that electrolyser has potential ability to operate under a variety of scenarios. It can be incentivised by predetermined ToU pricing tariffs, operate under constrained network with capacity limitations as well as help utilize renewable energy resources.

The Aberdeen Hydrogen Project successfully fulfilled its goal to evaluate behaviour of electrolysers under different operational constraints and commercial arrangements, and showed its potential to act as flexible load. In that way, it can be linked with renewable resources to reduce curtailment, but also participate in provision of various ancillary services. However, to ensure sufficient flexibility, hydrogen filling stations need to have adequate tank storage, so to enable production during times when it is beneficial to all involved parties, while respecting all operational constraints including its possible contracted obligation to participate in provision of balancing services.

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