INFLUENCES OF A HYDROGEN ELECTROLYSER DEMAND ON DISTRBUITON 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 decreasing the CO_2 emission in energy sector and road transportation. Aberdeen Hydrogen Project carried out by SSEPD is LCNF Tier 1 project 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_2 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 deliver 100% renewable electricity by 2020 [1]. A big contribution to the reduction goal can come from decarbonizing road transportation and energy sectors. Typically Eclectic Vehicle are regarded as an important part of sustainable future, and Fuel Cell Electric Vehicles (FCEVs), can be an alternative to EVs powered by batteries. Comparing to traditional vehicles powered by diesel/petrol, FCEVs have a relatively low carbon dioxide emissions. According to a UK government study presented in UK H2Mobility report [2], the carbon emission produced by a hydrogen fuel cell EV can be 75% less than the equivalent diesel vehicle in 2030. Thus, there is a potential to replace fossil fuelled cars with FCEVs, and the UK H2mobility report estimates that there will be 1.6 million FCEVs powered by hydrogen by 2030. This will require development of support 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 able to achieve this goal by 2030.

The hydrogen for transport summary report [3] proposed a number of ways of hydrogen generation, including large central water electrolyser, small distributed water electrolyser and central SMR (steam methane reforming). As summarised 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.

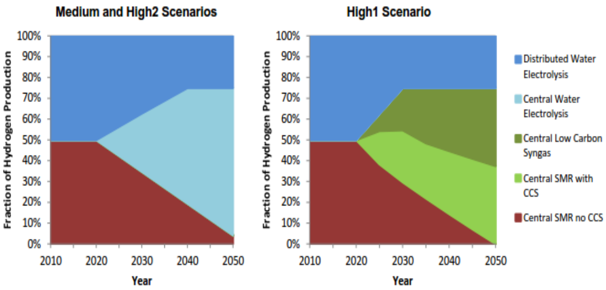

Figure 1. Hydrogen production mix scenarios [3]

However, production of H_2 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 operation and find incentives to coordinate their operation so to avoid adding significant load during peak hours. In addition, production of hydrogen can be regarded as a flexible load since H_2 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 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 and thus obtain additional revenue stream. 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 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 [2] 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 fuel cell EVs. In order to evaluate effects of penetration of FCEV on distribution network, SSEPD has carried out Aberdeen Hydrogen Project (AHP), which is LCNF (Low Carbon Network Fund) Tier 1 project. The purpose of the full project was to research past and present hydrogen projects and extract all the relevant learning in the context of producing hydrogen via electrolyser for the use in hydrogen FCEVs, especially where integrated with renewable generation. In addition, to support the use of electrolyser as a network service it is necessary to understand how it could be controlled and integrated with renewable generation in a constrained electrical network.

As part of the AHP the 1MW electrolyser, owned by BOC and consisting of 3 units, 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 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 ran 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 minimizes cost of operating electrolyser, and (ii) those that maximizes utilization of renewable energy. Time of Use (ToU) energy pricing scheme is applied in several trials when the objective considers operational cost. As for constrains, 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 is linked with each of the three electrolyser units, and instructs them when and how to operate. Moreover, electrolyser is connected to the hydrogen tank storage which has maximum and minimum levels of stored H_2. These storage tanks are used for bus refuelling, and levels of stored H_2 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_2 levels at the end of the trial. If this cannot be achieved, then the BOC emergency fill procedure takes over the control and operates electrolyser so to produce hydrogen at sufficiently high rate regardless of other trial objectives. In addition, it has been observed that there is a lower limit of electrolyser operating power level, which, if violated, can lead to electrolyser cycling due to low energy supply.

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_2.

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.

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		✓	✓						✓

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

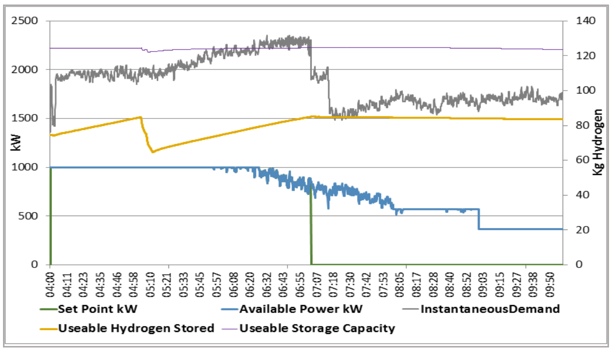

Figure 2. One Scheduling Results for Trial D

Trial D is a typical trial which considers optimal cost of running the electrolyser in a 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. In this case, the operation of electrolyser considers ToU tariff as well. 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. The available power (blue line) in Figure 2 is decreasing over trial time (from off peak to peak period). Set points in this trial (green line) follow the available power, and at these times the electrolyser is generating H2. 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 only for 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.

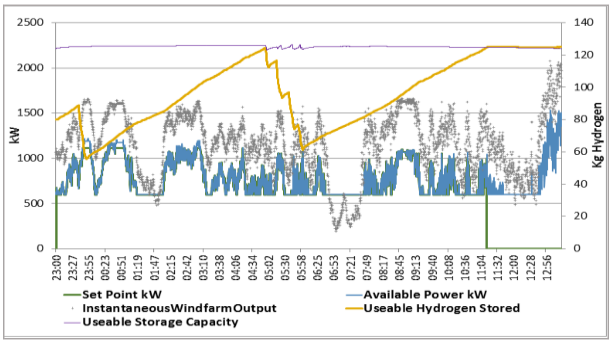

Figure 3. One Scheduling Results for Trial F

Objective of trial F, shown in Figure 3, is to utilize the ‘spill’ wind power to generate H_2 while respecting a capacity limitation in the local network. The amount of ‘spill’ energy is the energy that would have to be curtailed as it exceeds the local generation capacity. If electrolyser uses this energy to produce hydrogen, then the level of curtailment would be reduced. It can be noticed in Figure 3, which shows one instance of trial F, that hydrolyser effectively follows and uses available ‘spill’ wind power, while considering the local generation limit and satisfying the local demand. 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 Figure3 that this baseload constraint has been activated (and respected) few times during the trial period.

Furthermore, it can be observed that the process of producing hydrogen is slower (yellow line) when the available wind energy is lower. The H_2 stored in the tank reaches its target amount at 123 kg (set for this particular instance of trial) before the end of the trial, while the overall power consumed by the electrolyser is within the local generation limitations.

In the above described trials, their first priority is to satisfy demand for H_2 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 so.

Trial results showed that the electrolysers can respond to the control signal in a short time once they are warmed up. 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 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_2 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_2 demand, and also evaluate the optimal size of storage tanks.

BENEFITS TO DIFFERENT STAKHOLDERS

It is observed from the trial results that electrolyser can provide benefits to integration of renewables by utilizing energy produced by these resources, especially during times then wind or PV generators would have to be curtailed.

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, however, this is outside of the influence of Distribution Network Operators and calls for developing appropriate signals and pricing of network utilisation.

In addition, electrolyser can respond and change its consumption relatively quickly once it has been warmed up. Thus, it can help balancing the generation and demand and participate in provision of ancillary/balancing services [4]. 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 trial 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 constrains 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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