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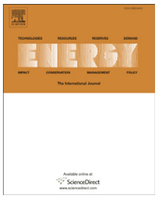

Development of a pricing mechanism for valuing ancillary, transportation and environmental services offered by a power to gas energy system

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ABSTRACT

Power to gas is a novel energy storage concept that can help in providing energy storage and offer sustainable and efficient alternative ways to utilize the surplus electricity generated by the provincial grid of Ontario, Canada. This situation of 'surplus electricity' also exists elsewhere as there in increasing intermittent renewable power on various grids. The ability of the power to gas energy hubs to utilize the existing natural gas distribution and storage network (within the province) to distribute and store the electrolytic hydrogen produced is one of its major advantages. In this study an optimization model of a power to gas energy hub having a hydrogen production module capacity of 2 MW has been developed. The goal of the optimization study is to carry out an economic feasibility of the energy hub under existing pricing mechanisms for the three primary services that it provides, namely: 1) Offsetting CO_2 emissions at natural gas end users by providing hydrogen enriched natural gas; 2) Providing demand response when directed by the Independent Electricity System Operator of the province, and 3) Providing pure hydrogen to a fuel cell vehicle refueling station. It is observed that current pricing mechanisms are not valued high enough for the power to gas energy hub to be economically feasible and payback periods longer than the project lifetime (20 years) have been observed. Therefore, through a post-processing economic calculation, the additional monetary incentive required for the energy hub to achieve a NPV equal to zero for shorter project lifetimes of 8, 9 and 10 years have been calculated. The required additional monetary incentives (for the new project lifetimes) have then been split proportionally to the share of the revenues earned by the energy hub while providing each of the three services. Through this, the existing pricing mechanisms have been scaled up and a new pricing mechanism has been developed that highlights the monetary requirements of a power to gas energy hub to be economically feasible. It is seen that the required increase in the pricing of the three different services offered by the energy hub are reasonable and lie within the ranges proposed for them in coming years.

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1. Introduction

With the ever increasing supply of electricity from green energy, many jurisdictions including the province of Ontario must balance an intermittent sources of renewable energy (wind and solar), whose generation profile at times do not match with the electricity demand profile. Furthermore, due to the current electrical system's high reliance on nuclear energy, there is a surplus of baseload power generated during certain off-peak periods. This surplus is often sold to neighboring jurisdictions at a loss in order to balance the power on the grid. One method for management of the supply and demand is to operate the renewable generation assets by making it dispatchable, as Ontario has had to do [1,2].

Research on potential implementations of large scale energy storage technologies in countries with growing renewable energy portfolio has been rigorous in the past few years. de Boer et al. [3]

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carry out a comparative analysis of the benefits of the integration of large scale energy storage systems like pumped hydro storage, compressed air energy system and power to gas energy hubs in an electricity grid with growing penetration of wind farms. In their rigorous analysis it is seen that the power to gas energy hub concept can be effective energy storage systems in countries which have existing natural gas systems that can act as a sink to store large amounts of surplus electricity.

The Independent Electricity System Operator of Ontario has been actively trying to procure energy storage technologies to help alleviate the surplus electricity generation issue that it faces during the power grids transition to a renewable energy economy. Power to gas is one of the technologies procured by the IESO [4].

Power to gas proposes to utilize surplus electricity produced by the power grid to produce hydrogen through electrolysis. The hydrogen can be injected into the existing natural gas distribution and storage system within the province and in this manner the natural gas grid is used for energy storage which helps to support renewable energy integration [5]. Linking the natural gas grid with the power grid will enable Ontario to utilize the large storage capacity offered by the existing underground natural gas reservoir. Walker et al. benchmark power to gas with respect to other existing energy storage technologies (in the context of Ontario) and highlight that the concept has a potential storage capacity that is orders of magnitude greater than competing technologies [6]. They also highlight the power to gas's ability to provide energy storage over a longer time period (weeks or seasonally). The hydrogen injected in to the natural gas grid can also find direct end use at natural gas end users. Nastasi et al. [7] analyze the benefits of linking the power and natural gas grids by suggesting an effective way of utilizing intermittent power generated by renewable energy storage systems. In their work Nastasi et al. look at the 'greening' of the natural gas grid by injecting renewable hydrogen produced via electrolyzers into the natural gas distribution network. The hydrogen enriched natural gas blend produced, helps in offsetting CO_2 emissions at the natural gas end user and is seen as a more efficient way of using hydrogen in comparison to its storage and re-use at a later time point to produce electricity. The linking of the heating and the electricity network is a potential solution for easing the transition to a renewable energy economy and forming a seamlessly interlinked energy network or a 'smarter energy network'. Collet et al. [8] carry out an environmental and techno-economic analysis on yet another potential energy recovery pathway of the power to gas energy hub concept where, hydrogen produced from both renewable and non-renewable energy sources is combined with CO_2 from biogas to produce bio-CH_4. The bio-CH_4 can then be injected in to the natural gas distribution network once it meets the specific standards set by natural gas utilities for it to be used by the end user. Maroufmashat et al. look at the feasibility of incorporating a Power to gas energy hub in an urban community and their analysis shows how different energy vectors including hydrogen can be exchanged between hubs, thus forming smart urban energy systems [9]. Although there are a number of pilot plants using power to gas globally, few of these use the injection of hydrogen into the natural gas system [10]. Only a small number of pilot plants worldwide use natural gas pipelines or underground gas storage reservoirs to distribute and store the gas. However, a power to gas plant in Falkenhagen, Germany demonstrates that this type of hydrogen injection is viable [11].

Also, the development of hydrogen generation capacity initiates a transition to a 'hydrogen economy' where zero emission transportation addresses both urban air pollution and climate change issues.

The ancillary service market can provide additional revenues for power to gas facilities with modern polymer electrolyte membrane (PEM) electrolyzers which can alter their load and output quickly in order to provide this service. To determine the appropriateness of electrolyzers for offering regulation and load following services, Eichman et al. [12] carried out ramping tests. The tests were carried out on a 40-kW alkaline and a 40-kW PEM electrolyzer. The results show that a polymer electrolyte membrane (PEM) electrolyzer takes less than ½ a second to complete almost all of a 25% ramp down from its maximum operating level to a lower operating level. Eichman et al.'s work also shows that it takes ½ a second for the PEM electrolyzer to complete a 75% ramp up from when the electrolyzer was turned off, and restarted again within a quick succession. The alkaline electrolyzer lagged the PEM electrolyzer significantly in the study and is thus less suitable for providing demand response services. The provision of high value ancillary services help to make the installation and operation of electrolysis technology more economical.

There are a number of disturbances that can lead to a disjoint between energy supply and demand [13]. To accommodate the disturbances and manage the grid, the Independent Electricity Systems Operator (IESO) purchases ancillary services from generators and consumers [14–18]. Ancillary services can be divided into operating reserves (OR) and demand response (DR), as shown in Table 1.

As can be seen from Table 1, the goal of the demand response program is to procure loads which react to signals to modify their energy use. One way to encourage a modification of energy use is to provide a price-based program [19,20]. This system mimics the nature of the Time of Use energy pricing for residential consumers in Ontario, and of the wholesale Hourly Ontario Energy Price (HOEP) for industrial and commercial consumers [13,21]. The eventual goal in Ontario is to have various demand response contractors bid through an auction to provide demand response services, as laid out by IESO's pre-auction report [22,23].

Although there are costs from offering demand response services, such as lost business and inconvenience, end users offering the service may have reduced total electrical costs from the use of low cost off-peak power [20,24,25]. When a high amount of energy demand is shifted to off-peak periods, it becomes easier to utilize renewable energy and manage the province's baseload nuclear power and makes more efficient use of all generation assets. The benefits are not only limited to the customers, but also extends to the operator of the program. If the IESO purchases demand response services from multiple loads, it will reduce electricity prices and its own capital and operations costs [26]. The IESO hopes to reach a demand response capacity of 80 MW through a number of contracts for loads up to 35 MW [18].

Parra et al. [27] carry out a techno-economic evaluations of power to gas energy hub systems with hydrogen production (electrolyzer system) capacities in the MW scale. One of the conclusions of their study shows the benefit of developing power to gas energy systems that can provide multiple services like: 1) Power to Hydrogen, and 2) Power to Methane. By offering multiple services, Parra et al. show that power to gas energy systems can become more economically viable.

Therefore, this study focuses on modeling a 2 MW power to Gas system, co-located at a natural gas pressure reduction station that offers three services, namely: 1) Offsetting CO_2 emissions at natural gas end users by providing hydrogen enriched natural gas; 2) Providing demand response when directed by the Independent Electricity System Operator of the province, and 3) Providing pure hydrogen to a fuel cell vehicle refueling station. A mixed integer non-linear programming problem has been formulated in the General Algebraic Modeling System (GAMS). The objectives being optimized are the economic performance, and the economic benefits from curbing the emission of greenhouse gases from the hub,

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