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Benchmarking and selection of Power-to-Gas utilizing electrolytic hydrogen as an energy storage alternative

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ABSTRACT

Power-to-Gas is an energy storage and transportation technology which is useful for the development of the ‘smart grid’, including the integration of intermittent renewable energy sources through the provision of energy storage capacity. To accomplish this, surplus or intermittent power is used to produce hydrogen via water electrolysis. As hydrogen is an energy vector, converting the power into gaseous hydrogen is considered to be an effective energy storage alternative. Previous studies attempt to qualitatively compare energy storage technologies considering criteria such as market maturity, efficiency, and cost, and include energy storage systems such as electrochemical batteries, pumped hydro or compressed air energy storage systems. In this work an Analytical Hierarchy Process is applied to compare Power-to-Gas with other energy storage technologies in applications ranging from residential load shifting to bulk energy storage and utility-scale frequency support. The authors find that Power-to-Gas is desirable in utility scale energy storage applications where criteria such as energy portability, energy density and ability for seasonal storage are considered.

Introduction

The integration of clean, renewable energy sources into the electrical grid, to counteract the harmful effects that fossil fuel based energy systems have on the global climate, creates an increased demand for energy storage. In the Canadian province of Ontario, for example, an overhaul of the electrical grid has begun, with a focus on increasing the use of renewable energy sources. In 2013, approximately 27% of Ontario's energy supply came from renewable sources, mostly made up of large-scale hydro facilities. However, Ontario's renewable energy generation has also increased due to heavy investments in solar and wind farms through a ‘Feed in Tariff’ program [1]. This increased use of renewable energy is essential to reducing greenhouse gas emissions from power generation. Due to a significant, constantly running nuclear base load generation capacity, and intermittent wind and solar renewable energy, the grid may become prone to prolonged periods of surplus power generation, and transmission capacity congestion at peak demand periods. Generally, in jurisdictions like this, surplus power is sold at a greatly reduced value, sometimes at even at a negative cost, in order to balance the system. According to

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the Independent Electricity System Operator (IESO), close to 18.3 TWh of surplus energy was exported from Ontario to neighboring jurisdictions at an undervalued cost in 2013 [2]. If this energy was stored approximately 1,396,000 houses could have been powered for an entire year, assuming an average monthly household energy consumption of 800 kWh [3]. The combination of this excess base load and new renewable energy sources is a driving force for the research behind assessing the feasibility of large scale energy storage systems.

Finding a solution to this problem means examining a number of different energy storage technologies including batteries, supercapacitors, flywheels, compressed air energy storage (CAES) and superconducting magnetic energy storage (SMES), among others. In practice, however, most of these technologies are not practical for storing large amounts of power for long durations. In addition, most of these technologies do facilitate energy portability, so there is often a mismatch between the demand generation locations. In contrast, using Power-to-Gas to store energy storage is attractive for seasonal storage applications where energy is produced at times of low demand, such as the Canadian winter, and saved for use during high demand days in the summer. By utilizing excess energy to produce hydrogen via water electrolysis, energy can be stored and distributed in the existing natural gas system for use when and where it is needed. Additionally, the generation of hydrogen by Power-to-Gas facilitates the integration of renewable energy, like solar or wind power [4].

As Mazloomi and Gomes [5] note, hydrogen is an efficient energy carrier with low losses in transit in comparison to the electrical grid. This bodes well for hydrogen's future use as a transportation fuel [6]. Indeed, many vehicle manufactures are releasing commercial hydrogen fuel cell vehicles for the period 2025–2030 [7]. To facilitate this, Power-to-Gas utilizes the hydrogen produced as an energy vector, or as a form of energy that can be efficiently stored and transported, as well as used as transportation fuel. The remainder of this examination of Power-to-Gas is organized as follows: in the next section, the issues facing the traditional electrical transmission grid system are discussed in detail. Following this, an overview of Power-to-Gas and other energy storage technologies and their potential applications are given. Next, the Analytical Hierarchy Process is introduced, defined and applied to choosing energy storage technology to possible applications. Finally, the results are given and discussed for this analysis.

Traditional electrical transmission grid system

In the last 10 years, due to economic recession, there has been an overall decrease in the growth electrical demand. However, over the last 40 years energy demand has risen and this trend is expected to continue. In particular, Canada's energy demand increased by 70% from 1980 to 2010, but decreased by 10% since 2005 due to the ever-increasing population and economy [8]. The recent 10 year decrease can be accounted for by decreased economic activity, the replacement of old, inefficient devices with new, more efficient ones at the user level and improved demand-side management. Programs to accomplish demand-side management include incentives for energy customers and a decrease in dependency on external power sources by industry. Incentive programs are useful for increasing the adoption of energy efficiency devices by companies, communities and homeowners who decrease their energy costs while reducing or shifting their energy demand. Further, industries that are dependent on energy for both power and heat have slowly begun to adopt combined heat and power systems (CHP) that use a single fuel to produce both energy and heat [1]. This strategy not only provides relief to the grid but is economically advantageous.

The supply of available electricity has grown about 13% in Ontario since 2003 [8]. Although the overall decrease in energy demand from users is a positive development, the variable nature of load profiles among energy users makes it difficult to efficiently manage the system. The amount of power generated by base load generation which is composed of primarily nuclear, hydro, and some gas-fired generation units, exceeds the demand for power during off-peak hours, thus leading to surplus generation. This excess electricity causes difficulties in managing the energy market as the energy supply needs to be continuously balanced with the demand. One of the side effects of excess generation is that energy suppliers are forced to bid lower prices in order to avoid being dispatched off or shut down [2]. This practice causes the Hourly Ontario Energy Price (HOEP) to drop significantly, often falling below zero dollars, meaning that suppliers are paying other energy consuming jurisdictions to use their electricity. However, provincial consumers do not benefit from the decrease in price as the generation authority adds a 'Global Adjustment Charge' (GAC) to electrical bills [9]. This additional charge is calculated from the difference between the contractual rates paid to the regulated generators of electricity and the wholesale market price set by organizations like the Independent Electricity System Operator (IESO) [10]. A supplementary charge is also added to the GAC to support the conservation program which gives 'financial assistance to new and innovative electricity conservation initiatives designed to enable Ontario's residents, businesses and institutions to cost-effectively reduce their demand for electricity' [11].

Power-to-Gas for energy storage

Power-to-Gas energy storage systems, as mentioned earlier, can play a key role in dealing with the issue of surplus base load and fluctuating renewable energy generation within the province of Ontario. Gahleitner [12], lists some of the Power-to-Gas pilot plants that exist around the world. Although most of them involve producing electrolytic hydrogen and storing it in hydrogen tanks, some of them also make use of natural gas pipeline and underground gas storage reservoirs to distribute and store the gas for longer periods of time. One example, is the Power-to-Gas plant in Falkenhagen, Germany which began operation in 2013 [13]. The plant, which was developed by E-ON in partnership with Hydrogenics, who provided the electrolyzer technology, is a 2 MW energy storage