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Investigating the effect of renewable energy incentives and hydrogen storage on advantages of stakeholders in a microgrid

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ABSTRACT

The objective of this research is to investigate the effect and cost-efficiency of different renewable energy incentives and potential for hydrogen energy storage to the perceived viability of a microgrid project from the prospective of different stakeholders, i.e., government, energy hub operators and consumers in Ontario province, Canada. Hourly simulation of a microgrid in which wind and/or hydrogen are produced is used for the analysis. Results show that using underground seasonal storage leads to the government paying less incentive per kg of CO_2 emission reduction as it lowers levelized cost of hydrogen and provides a higher carbon emission reduction potential. Results also show that for the same incentive policy, incentivizing hydrogen production with grid electricity or a blend of wind power and grid electricity and producing hydrogen using wind power with underground hydrogen storage are more cost-efficient options for government than incentivizing wind power production alone. Regarding the renewable energy incentives, a combination of capital grant and FIT is shown to be more cost-efficient incentive program for the government than FIT only programs. However, FIT programs are more effective for promoting renewable energy infrastructure.

1. Introduction

The growth in the level of CO_2 emissions has been a challenge worldwide. CO_2 emissions from energy account for the largest share of global GHG emissions which was about 60% of global emissions in 2010 (Statistics, 2016). The world's energy consumption and CO_2 emissions are expected to increase by 56% and 46% between 2010 and 2040, respectively (US Energy Information Administration, 2013). Despite the importance of renewable energies in overcoming this challenge, successful integration of such energies can only be achieved after overcoming varied obstacles. One important obstacle here is the need for investment capital. Investment in renewable energy projects requires financial incentives because such projects not only have typically higher capital costs than the conventional energy generation methods, but also are in some cases considered to be riskier due to technology and resource uncertainties. In fact, renewable energy projects are generally of a smaller scale in comparison with the conventional energy production projects and consequently could not benefit from economies of scale (Abdmouleh et al., 2015). The objective of this research is to determine how different incentives contribute to the perceived viability of a microgrid project from the prospective of different stakeholders, i.e., government, energy hub operators and consumers and also to examine the potential for hydrogen energy storage within a microgrid. Previous studies have examined the implementation of new distributed energy technologies confounding the objectives of all stakeholders. However, in a society the entity that will invest in and implement a new distributed energy generation and transformation technology is a commercial firm with their own motivations independent of other stakeholders. Unique to this work, is analysis of motivations of each stakeholder independently, which will allow for better policy development and increase implementation of distributed energy technologies.

To overcome the problem of higher investment capital for renewable energy projects, many countries all over the world have started incentive programs through different policies to reduce emissions from power generation sectors. Some of the common policies which aim to expand renewable energy infrastructure include carbon taxes, Feed-In-Tariffs (FIT), premium payments, quota systems, auctions, cap and trade systems and capital grants. Different policies have contributed to reducing Greenhouse Gas (GHG) emissions through incentives provided

Abbreviations: GHG, Greenhouse Gasses; CAD, Canadian dollars; $kgCO_2$, Kilograms of carbon dioxide; kg, Kilogram; kWh, Kilowatt-hour; MWh, Megawatt hour; GWh, Gigawatt hour; kW, Kilowatt; hr, Hour; s, Second; m, Meter; HHV, Higher heating value; FIT, Feed-In-Tariffs; FIP, Feed-In-Premiums; NG, Natural Gas; HENG, Hydrogen Enriched Natural Gas; ICE, Internal Combustion Engine

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to renewable energies; however, the remaining question is how to define, combine and use incentives in the most profitable manner to face the new challenges in the development of renewable energy. The importance of this question emerges from the fact that there are several renewable energy technologies developed with different characteristics such as efficiency, cost, capacity factor, and availability. At the same time, there are several programs to incentivize the renewable energy technologies and each of these incentives may benefit certain technologies or stakeholders in an energy system. Although some research has been dedicated to development of renewable energy technologies, finding the most efficient policies and methods for increasing the penetration of renewable energies into national energy systems has attracted less attention and has yet to be further investigated (Fischer and Preonas, 2010).

This research aims to develop a simulation model of a microgrid in which hydrogen and wind power are produced via different operational scenarios. This simulation model is used to investigate the cost-efficiency and effect of renewable energy incentive schemes on the advantages of each system for different stakeholders interacting in the microgrid. The analysis is done in the context of distributed generation. Such context was chosen for the analysis because of an increase in penetration of distributed generation in developed countries and the significant role it is expected to play in future electricity supply. Distributed generation can substantially reduce carbon emissions, thereby contributing to the commitments of most developed countries to meet their greenhouse gas emissions reduction targets. These targets are typically set based on the Paris Climate Accord within the United Nations Framework Convention on Climate Change (UNFCCC) which deals with GHG emissions mitigation, adaptation and finance starting in 2020. Also, the presence of energy generation and storage close to the energy demand may increase the power quality and the reliability of electricity delivered to sensitive end-users. An important factor in increasing the penetration of distributed generation has been the restructuring of power markets (Tsikalakis et al., 2006).

While the application of distributed generation can potentially reduce the need for traditional electrical transmission system expansion, managing a potentially huge number of distributed generation facilities creates a new challenge for operating and controlling the network safely and efficiently. Note that offsetting transmission system expansion benefits government stakeholder, but does not specifically benefit the end-user. This challenge can be partially addressed by microgrids (Hatziargyriou et al., 2007). Microgrids are low voltage distribution networks comprising various distributed generators, storage devices and controllable loads that can operate interconnected or isolated from the main distribution grid, as a controlled entity (Tsikalakis et al., 2006). Microgrids coordinate distributed generation facilities in a consistently more decentralized way, thereby reducing the control burden on the grid and permitting them to provide their full benefits (Hatziargyriou et al., 2007).

In the microgrid proposed in this work, hydrogen is produced via electrolysis using grid electricity and/or wind power. Wind power has been considered a promising substitute for conventional sources of electricity because of its abundance, adaptability to the existing land use, nonpolluting character, and increasing cost effectiveness (Jami and Walsh, 2016). Additionally, among all hydrogen production pathways, electrolytic hydrogen production via wind power is considered to have the lowest GHG emissions. Moreover, wind energy has the lowest levelized cost of electricity among renewable energy sources after hydropower (Olateju et al., 2014). As a result, production of electrolytic hydrogen via wind power seems to be of noticeable potential.

Using hydrogen energy for storing and transporting energy has attracted great attention. For instance, European Union launched a joint technology initiative to spend almost 1 billion € over six years for hydrogen and fuel cells technologies (New Energy World IG, EC, 2008; Council of the European Union, 2008). Electrolytic hydrogen not only can replace fossil fuels in both industrial and mobility demands, but also can be used as a practical option for storing large amounts of power for long durations of time (Mukherjee et al., 2015). The use of electrolytic hydrogen production as energy storage that uses the existing natural gas (NG) distribution system is defined in the concept of Power-to-Gas. Power-to-Gas concept proposes to convert the surplus electrical energy to chemical energy by producing hydrogen which can then be directed in multiple application pathways (Walker et al., 2016). The block diagram of the Power-to-Gas concept is shown in Fig. 1.

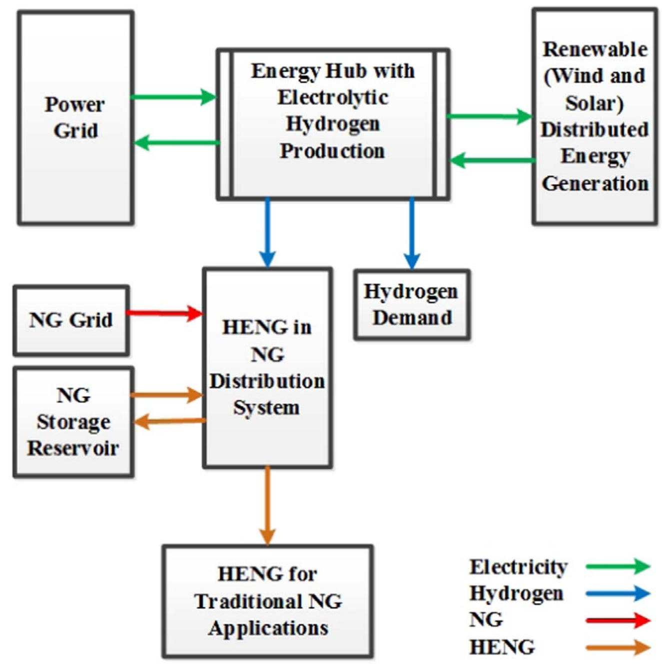

Fig. 1. Power-to-Gas concept block diagram.

Fig. 2 shows Ontario's electricity supply mix for 2015. As it can be seen, about 90% of Ontario's electricity supply is generated from fossil free resources. Hydrogen generation provides energy storage benefits to make maximum use of the clean energy in the electrical grid.

de Arce and Sauma (2016) for instance, compared different incentive policies (carbon tax, FIT, premium payment and quota system) for development of renewable energy in a modeled simplified radial power network, using price-responsive demand. The incentive schemes were compared at different congestion levels in terms of energy prices, renewable energy generation, CO_2 emissions, and social welfare. The authors found that subsidy policies (FIT and premium payments) are more cost-effective in reducing CO_2 emissions than those policies that apply penalties or taxes when assuming oligopoly competition and that

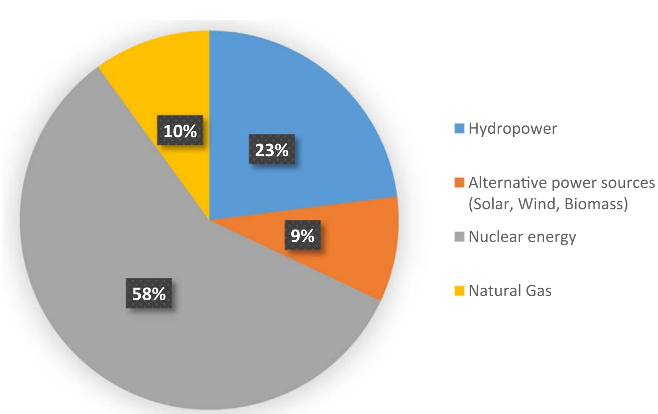

Fig. 2. Ontario's electricity supply for total delivered energy 2015 (Ontario Energy Board, 2016).