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Techno-Economic Evaluation of Hydrogen Fuel Cell Electricity Generation Based on Anloga (Ghana) Wind Regime

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ABSTRACT

This paper assesses the performance of electricity generation using wind/hydrogen/fuel-cell technology. The intermittency of renewables, especially wind, and the need for storage of excess energy make them unattractive for continuous generation of electricity. This paper focuses on the wind resource of Anloga (Ghana) and the potential of hydrogen production from water electrolysis. The assessment of this system covers three main areas including the potential energy generation, environmental impacts, and economic impacts. The paper adopted analytical models of energy generation of fuel cell and hydrogen technologies and further performs their assessment using HOMER software. It was revealed that the annual electricity production from the hydrogen fuel cell is 25,999kW/yr, with an annual capacity shortage of 392kW/yr representing a 10% capacity shortage. The levelized cost of electricity was 0.602$/kWh and the emissions have been completely minimized as compared to diesel generation plants.

KEYWORDS

Fuel Cell, Hybrid Energy Supply, Hydrogen, Levelized Cost of Electricity, Proton Exchange Membrane, Renewable Energy, Storage, Wind

1. INTRODUCTION

Electricity generation through renewable means is a global trend today (Allan, Eromenko, Gilmartin, Kockar, & McGregor, 2015; Dogan, 2015; Kleineidam & Dörr, 2015; Lopatkin, Shushunova, Shaldina, Gibadullin, & Smirnova, 2019; Pérez-Denicia, Fernández-Luqueño, Vilariño-Ayala, Manuel Montaño-Zetina, & Alfonso Maldonado-López, 2017). Conventional methods of energy generation

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have gradually become unattractive due to the considerable greenhouse emission that contributes to global warming and the deterioration of the ozone layer.

Recently, lockdown measures due to the advent of COVID19 have reduced the demand of electricity globally and contributed to a change in the power mix. Even through domestic demand has increased considerably, they have been outweighed by commercial and industrial demand. The International Energy Agency (IEA) projects that global electricity demand will reduce by 5% and in some few situations, 10% and that electricity demand from conventional sources such as coal, gas and nuclear power will reduce considerably (IEA, 2020a). The IEA energy mix analysis further supports the assertion that low-carbon energy sources that include renewables would far outstrip conventional sources like coal-fired generation (IEA, 2020a).

The rising trend towards renewable energies is obstructed by lack of adequate technologies with high efficiency. According to the IEA, energy generation from non-combustible renewable has considerably increased to 2,734.7 TWh, accounting for 25.9% of the total OECD electricity generation, a figure that significantly surpasses coal-fired generation which was estimated at 2.327.6 TWh (IEA, 2020b). Solar photovoltaic which is the popularly adopted technology in West Africa, has efficiencies between 15 to 22% even though the resource is intensively available. There has not been much efforts done with the installation of wind turbines to harness energy through the conversion of wind speed but there are documented evidences of available and consistent wind speed in Ghana, capable of generating a sizeable amount of energy that can be used for community mini or microgrid.

There is no sizeable wind turbine installed in Ghana at the moment for the purpose of energy generation, even though there have been feasibility studies conducted by the Energy Commission to site some wind farms at specific locations in Ghana. The technology is promising with efficiencies higher than solar photovoltaic and become even more interesting when combined with hydrogen energy production.

Hydrogen production is an umbrella term indicating various methods used for hydrogen generation which is later used for electricity production (Acar & Dincer, 2019; Fajrina & Tahir, 2019; Kim, Hansora, Sharma, Jang, & Lee, 2019; Setiabudi, Aziz, Abdullah, Teh, & Jusoh, 2020; Shwetharani et al., 2020). Hydrogen can naturally be obtained from steam reforming or natural gas. They may also be encountered in naphtha or other industrial gases. Even though hydrogen is perceived as the most abundant resource on earth it is difficult getting it in pure form. It is always extracted from its compounds, a process that definitely consumes electricity. The advantage in the process of extracting hydrogen is that the electricity needed, can be provided by any primary source of energy including solar, wind or fossil fuels such as natural gas, coal or biomass. The diversity of potential supply sources makes hydrogen a promising energy carrier. A lot of research is being conducted globally into the means of extracting hydrogen more efficiently. However, two popular methods are currently used: water electrolysis and steam methane reforming. Electrolysis consists of splitting water into hydrogen and oxygen with energy input and heat. In the reforming process, natural gas like methane is converted to hydrogen through a reaction with either steam, oxygen (partial oxidation) or both. Hydrogen can also be obtained as a by-product of industrial processes such as production of caustic soda and chlorine.

Hybridizing renewables for energy production is a global trend nowadays as the benefits of hybrid renewables seem to overweight that of single renewable generation. This is however not achieved without referring to a number of optimization problems, usually solved with recent heuristic optimization solvers. An impressive number of these optimization solvers dealing with hybrid energy supply problems can be found in recent studies by Vasant, Zelinka, & Weber (2019) and Ganesan, Vasant, Sanghvi, Thomas, & Litvinchev (2020). In the case of hydrogen power generation, the challenge is to extract the hydrogen itself and store it, a process that requires energy supply, before generating energy through existing fuel cell technologies. Also, supplying energy directly with wind turbine has proven unreliable because of wind speed unpredictable variation and the incapacity of the system to supply energy at a peak load time. On major issue that remains unresolved in the

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