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Economic viability and production capacity of wind generated renewable hydrogen

M. Mohsin [a,*], A.K. Rasheed [b], R. Saidur [b,c]

[a] College of Economics and Management, Nanjing University of Aeronautics and Astronautics, 29 Jiangsu Avenue, Nanjing, 211106, China

[b] Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Science and Technology, Sunway University, Bandar Sunway, Petaling Jaya, 47500, Selangor Darul Ehsan, Malaysia

[c] Department of Engineering, Lancaster University, LA1 4YW, United Kingdom

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ABSTRACT

Generally, wind to power conversion is calculated by assuming the quality of wind as measured with a Weibull probability distribution at wind speed during power generation. We build on this method by modifying the Weibull distributions to reflect the actual range of wind speeds and wind energy density. This was combined with log law that modifies wind speed based on the height from the ground, to derive the wind power potential at windy sites. The study also provides the Levelized cost of renewable energy and hydrogen conversion capacity at the proposed sites. We have also electrolyzed the wind-generated electricity to measure the production capacity of renewable hydrogen. We found that all the sites considered are commercially viable for hydrogen production from wind-generated electricity. Wind generated electricity cost varies from $0.0844 to $0.0864 kW h, and the supply cost of renewable hydrogen is $5.30 to $ 5.80/kg-H_2. Based on the findings, we propose a policy on renewable hydrogen fueled vehicles so that the consumption of fossil fuels could be reduced. This paper shall serve as a complete feasibility study on renewable hydrogen production and utilization.

Introduction

Growing energy demands and climate regulations encourage the utilization of renewable energy resources including hydrogen energy. Continuous usage of fossil fuels will result in irrevocable damage of environment. Several nations around the globe are striving to provide clean and sustainable energy by 2030 [1]. Carbon based power systems should be exchanged with new renewable energy technologies that are able to balance energy demand-supply, ensure energy security, have less impact on climate change and economically viability. According to Renewable Global Status Report, renewable energy contributed 19.2% of the total world's energy consumption in 2014. Among the several renewable energy resources, renewable hydrogen could be a major contributor to sustainable clean energy production and successful Millennium Development Goals (MDGs) [2]. Intergovernmental Panel on Climate Change (IPCC) [3] considers renewable hydrogen energy (RHE) to be the best substitute for fossil fuels. Moreover, RHE would help to ensure 100% integration of renewable energy. RHE can be generated through

* Corresponding author.
E-mail address: mumu@nuaa.edu.cn (M. Mohsin).
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various resources such as wind, solar, geo-thermal and hybrid sources. RHE systems can improve energy security of developing nations [4] including China and Japan, and help them in reducing China's CO_2 emissions via scientific diversification, and minimizing dependence on imported fossil fuels.

Energy generation using solar systems typically costs 6 to 18 times higher than wind energy and wind turbine systems [5]. At present, hydrogen production through water electrolysis using wind energy is considered as a lowest life cycle greenhouse gases (GHG) emissions of all hydrogen production resources. Most works related to hydrogen production have ignored the regional characteristics of wind power potential to produce renewable hydrogen at country level [6]. Mostly traditional methodologies are adapted to select optimal wind sites and lack exploitation of latest technologies [7]. They have only used present value (PV) cost methods to measure the price of renewable energy. PV cost method combines discount rate and future cash flows, and it is hard to estimate the 100% accuracy of future value and discount rate. In addition, the PV cost method do not incorporate the increasing unit of energy production. Existing literature [8] partially enumerates the wind power potential, the cost of renewable energy and hydrogen production along with its capacity. Based on our knowledge, this is the first of its kind study that takes into account all the above-mentioned issues.

This study uses modified Weibull distribution function to characterize and select optimal wind sites and turbine configurations at a rich windy site to produce wind electricity for hydrogen production. We used a new modified model of the Weibull distribution function and log law, and electrolyze the wind-generated electricity to produce renewable hydrogen energy. Our paper additionally measures the Levelized cost of wind electricity generation via average incremental credit cost to measure the cost of renewable hydrogen production. The advantage of average incremental credit cost is associated with every increasing unit because, few costs are variable and some are fixed cost so the average incremental cost will decrease with increasing every unit of energy production. We also introduced a new mathematical model to measure the hydrogen production capacity at any windy sites by introducing the wind topography of Pakistan as a practical case study, which shows the total wind power potential. Based on our findings, we suggest a policy to the government to reduce the energy shortfall by shifting vehicles from fossil fuel to hydrogen energy. Our study also provides an empirical estimation, economic viability of the hydrogen production and guidelines for 100% integration of renewable energy. In summary, our objective is focused towards the potential generation of renewable hydrogen from the wind-generated electricity at windy sites and its economic integration is the main objective of the study.

Literature review

Numerous studies have investigated the integration and design of the renewable hydrogen energy systems. Measuring the availability of renewable energy resources for production of hydrogen with different statistical and mathematical calculations has been a common trend [9,10]. Olateju et al. [11], explored the production of wind generated hydrogen and determination of potential sites using the measurement of capacity factor by Weibull distribution function over wind. Østergaard et al. [12], stated that wind turbine and heated pump hydrogen storage system provides a continuous supply of energy when energy activity is slow. Katsigiannis et al. [13], examined the multi-criteria assessment for the potential of hydrogen production systems through wind energy, gas turbine and photovoltaic system. Sacramento et al. [14], conducted a study on electrolytic hydrogen production for the Ceara state in Brazil. They observed that the energy consumption and the gross internal product per capita of the region would increase by using the renewable resources to produce hydrogen. Ball et al. [15], stated that hydrogen production through renewable wind energy by electrolyzing the water without carbon dioxide emission or other dangerous gases leads to an optimal energy mix, resulting in reduced dependency on fossil fuels. Rodríguez et al. [16], assessed the potential of the hydrogen generation using wind energy in the province of Cordoba in Argentina. They found that the potential supply of wind energy to produce hydrogen energy in that region is ten times higher than the required level of hydrogen energy for the entire vehicular transportation. Bekele et al. [17] conducted a study to determine the feasibility of hydrogen production using wind energy. Guo et al. [18] examined a wind-energy storage-system model for huge wind energy of China. Akpinar et al. [19] investigated the wind characteristics of (Elazig-Keban, Elazig-Agin, Elazig and Elazig-Maden) by using probabilistic distributions, Maximum Entropy Principle, and traditional normal Weibull distribution through singly truncated application. Mohammadi et al. [20], used six statistical techniques including graphical method showing a weak efficiency while, Lysen empirical method, Justus empirical methods, maximum likelihood method, energy pattern factor method and modified maximum likelihood method shows a strong efficiency to determine the scale (c) parameters and shape (k) parameters of Weibull distribution function to measure wind power density. Ozay et al. [21], analyzed wind characteristics including wind direction, frequency distribution of wind speed, mean speed, scale and shape parameter of Izmir region in Turkey by using two parameter Weibull distribution function. Shu et al. [22], measured the characteristics of renewable energy sources of Hong Kong through traditional Weibull distribution function. Hill et al. [23], measured the parameters of Weibull probability and Weibull density distribution function for three different sites and found that statistical values of scale and shape parameters for these stations are wide-ranging. Tsekouras et al. [24], proposed probability distribution function by time series data. They estimated the distributional parameters of probability distribution function. Wais et al. [25], concluded that the accurate evaluation of Weibull shape and scale parameters is necessary for the wind energy potential estimation. Wind speed alone does not provide the clear understanding of wind speed distribution and wind potential of any sites in the region, because it is also possible that the same average wind speed have different parameters of Weibull distribution function. Khahro et al. [26], analyzed the numerical characteristics of wind speed to obtain an exact measurement and estimation of wind potential. They focused on wind

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