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Optimal design of a Hydrogen Refuelling Station (HRFS) powered by Hybrid Power System

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ABSTRACT

The use of hydrogen as transportation fuel is considered to be a favourable alternative to fossil fuels. It is believed that the development of fuel cell vehicles will greatly facilitate reduction of greenhouse gas emissions from the transportation sector due to the fact that these vehicles are fuelled by hydrogen, which can be produced by a wide range of processes using renewable energy sources. In order to promote the use of fuel cell vehicles, it is imperative to build the necessary facilities to support this need in the near future, including hydrogen refuelling stations powered by renewable power generation systems. In this study, techno-economic analysis was performed for a hydrogen refuelling station powered by two types of hybrid renewable power generation systems (wind-photovoltaic-battery and wind-battery systems) which will be installed on the island of Gökçeada, Turkey. The analysis was carried out to assess the feasibility of the hydrogen refuelling station to refuel 25 vehicles on a daily basis throughout the year, using HOMER software. Based on the results, the levelized cost of hydrogen for the hydrogen refuelling station powered by the hybrid wind-photovoltaic-battery and wind-battery systems is $ 8.92/kg and $ 11.08/kg, respectively. The levelized cost of hydrogen was also determined for different variable parameters (wind speed, wind turbine hub height, solar irradiance, and project lifetime). It is concluded that the hydrogen refuelling station powered by the proposed renewable power generation systems may be feasible for the chosen site.

1. Introduction

Global warming, climate change, escalating oil prices, and environmental pollution resulting from the widespread use of fossil fuels has made the utilization of renewable energy sources of great significance among the global community [1]. Internal combustion engines (ICEs), which account for almost 90% of energy demands in the transportation sector, are the major contributor towards environmental pollution [2,3]. Hydrogen has gained much attention as an alternative transportation fuel because it can be produced from primary and renewable energy sources. The production of hydrogen from renewable energy sources and its use in the transportation sector will significantly reduce carbon dioxide (CO_2) emissions and micro particles [4]. A large number of hydrogen-fuelled vehicle projects have been implemented from 1807 to the present day. In the last few years, vehicle manufacturers such as Toyota Motor Corporation, Nissan Motor Corporation, and Fiat Chrysler Automobiles have begun producing hydrogen-fuelled vehicles [5]. However, the transition from fossil-fuelled ICEs to environmentally friendly hydrogen-fuelled vehicles depends on the availability of technologies to produce hydrogen from cleaner, renewable, and sustainable sources as well as the wide availability of hydrogen refuelling stations [6].

Hydrogen can be produced by various methods, including steam reforming of natural gas, coal or biomass gasification, and electrolysis of water by supplying electricity produced from fossil fuel combustion, nuclear power, or renewable energy sources such as wind, solar, and hydro energy [7]. The two most common technologies for hydrogen production are natural gas reforming and water electrolysis [6]. Water electrolysis is a mature technology, which is used for hydrogen production capacities ranging from a few cubic centimetres per minute (cm^3/min) to thousands of cubic metres per hour (m^3/h). Water electrolysis is relatively efficient with an energy efficiency of more than 70% [8]. The use of renewable energy sources for hydrogen production by water electrolysis is advantageous because it reduces environmental pollution. On-site hydrogen refuelling stations offer a practical means of supplying hydrogen on a small scale compared with central hydrogen production stations, which require significant capital investment to build a reliable hydrogen transport and delivery infrastructure [6,9].

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Thus, an effective integration of on-site hydrogen refuelling station with renewable energy technologies such as hybrid wind-solar energy systems is needed to provide accessibility to this clean fuel in isolated and remote areas.

Modelling a power generation system before realizing a project is crucial for decision-making and pre-feasibility analysis. Various commercial and free software tools have been used by researchers to assess the technical and economic feasibility of power generation systems, such as Hybrid Optimization of Multiple Energy Resources (HOMER) software (HOMER Energy LLC, USA) and RETScreen software (Natural Resources Canada, Canada) [10]. Despite the large number of studies published on renewable energy systems, there are only a few studies focused on the integration of hydrogen production systems with renewable energy technologies for small-scale or large-scale hydrogen production. Siyal et al. [1] performed techno-economic analysis of a wind-powered hydrogen refuelling station with the capacity of refuelling 200 vehicles at three sites in Sweden. Based on the results, the levelized cost of hydrogen (LCOH) ranges from $ 5.18/kg H_2 to $ 9.62/kg H_2 for the hydrogen refuelling stations investigated in their study. Das et al. [11] studied the feasibility of hybrid renewable energy systems (photovoltaic (PV) arrays, batteries, and fuel cells) in Sarawak, East Malaysia, in order to determine the best configuration of power systems for electricity production. The results showed that the cost of electricity was $ 0.323/kWh for the optimum PV-battery system whereas the cost of hydrogen production for the fuel cell system was $ 99.9/kg. Posso et al. [12] analysed the technical potential of hydrogen production powered by renewable energy systems (solar, wind, geothermal, and hydro energy) in Ecuador and the technical potential was found to be $4.55(10^{8})$ kg/year. They found that the solar PV panels contributed the most towards hydrogen production. Rahmouni et al. [13] analysed the technical potential of hydrogen production in Algeria. The total annual hydrogen production was $2.4(10^{5})$ and $2.1(10^{5})$ tons/km^2 for the solar-powered and wind-powered hydrogen production, respectively. Viktorsson et al. [14] analysed the technical and economic potential of an on-grid hydrogen refuelling station powered by a hybrid wind-solar system in Halle, Belgium, and the LCOH was determined to be €10.3/kg. Al-Sharafi et al. [15] studied the potential of electricity generation and hydrogen production of hybrid PV-battery-wind-fuel cell systems installed at different locations in the Kingdom of Saudi Arabia. The results showed that the levelized cost of energy (LCOE) and LCOH were $ 1.208/kWh and $ 43.1/kg, respectively, for the hybrid PV-wind-fuel cell system.

Akyuz et al. [16] conducted a case study to analyse the probability distribution of hydrogen production for PV-supported proton exchange membrane (PEM) electrolyser system. The cost of hydrogen production in Balikesir Province, Turkey, was determined to be $ 43.9/kg. Grenier et al. [17] presented a method (which involves chronological simulations and economic assessment) to assess the feasibility of wind-hydrogen energy systems for hydrogen production on one of the islands in Norway with the aim of using these systems in hydrogen-fuelled ferry. The cost of hydrogen production was calculated to be € 2.8/kg and € 6.2/kg for the grid-connected and isolated systems, respectively. Rodrigez et al. [18] analysed the technical and economic potential of a wind-power system for hydrogen production in the transportation sector in the Córdoba Province, Argentina, taking into account the electrolyser efficiency and capacity factor of the wind-power system. They concluded that the wind-power system is capable of fulfilling the load demands of the electrolysis-based hydrogen production system to fuel hydrogen-fuelled vehicles. Akyuz et al. [19] analysed the solar radiation and wind data in Balikesir Province, Turkey, in order to size and determine the energy efficiency and hydrogen production capacity of the hybrid renewable power generation system. They concluded that the capacity of each component in the proposed system needs to be set in order to determine a feasible solution for the hybrid renewable power generation system. Santoli et al. [20] carried out a study to realize a small-scale hydro-powered methane production system in Italy. They simulated twelve scenarios using HOMER software and the lowest LCOH was obtained for the optimum system configuration, with a value of € 8.041/kg. There is a positive growth of hydrogen refuelling stations for land transportation in recent years [1] and therefore, there is a critical need to determine the optimum configuration of hybrid renewable power generation system for on-site hydrogen refuelling station in order to supply fuel for fuel cell vehicles.

In line with the above motivation, techno-economic analysis was carried out in this study to assess the feasibility of a stand-alone hydrogen refuelling station powered by a hybrid renewable power generation system in order to fulfil the hydrogen demands on the island of Gökçeada, Turkey, as a first step towards the elimination of fossil fuels in the transportation sector. Two hybrid renewable power generation systems were modelled to supply hydrogen to the hydrogen refuelling station: (1) wind-PV-battery system (Case 1) and (2) wind-battery system (Case 2). HOMER software was used to determine the optimum configurations of the hybrid renewable power generation systems under different scenarios.

2. Methodology

In this study, it was assumed that the hydrogen refuelling station powered by the renewable power generation system is located on the island of Gökçeada, Turkey, and this hydrogen refuelling station is designed to meet a hydrogen demand of 125 kg/day, which is sufficient to refuel 25 cars with a hydrogen tank capacity of 5 kg. Fig. 1 shows the

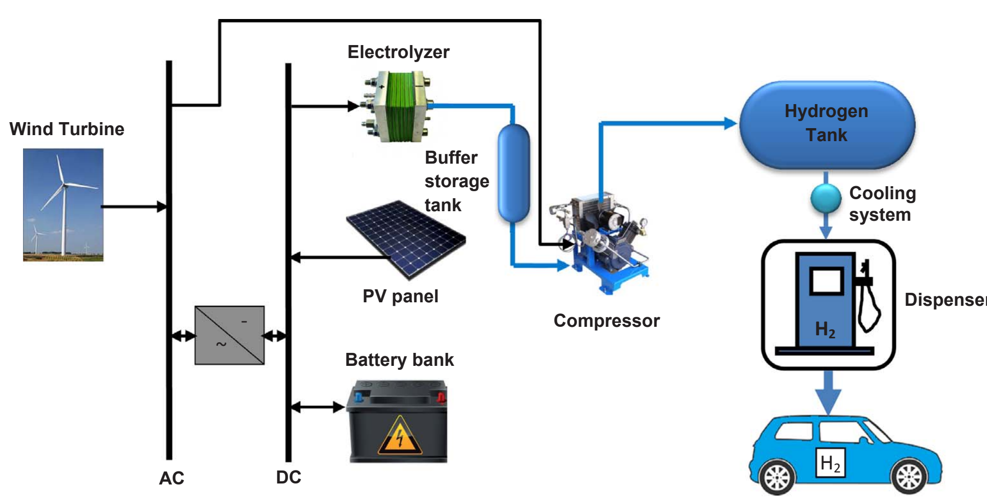

Fig. 1. Main components of wind-pv-battery & hydrogen systems.