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Techno-economic feasibility of a photovoltaic-wind power plant construction for electric and hydrogen production: A case study

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ABSTRACT

Hydrogen is one of these sources that no acceptable assessment of its technical - economic production feasibility has been done yet in various regions of Iran. Accordingly, the present study has been carried out aiming at technical-economic feasibility of establishing hybrid photovoltaic-wind power plant to produce electricity and hydrogen using Homer software for Hendijan area in the South West of Iran. The findings of the technical-economic feasibility study shows that the area under study annually produces 3,153,762 kW h of electricity for a Photovoltaic-wind power hybrid system, and 31,680 kg of hydrogen for constructing a hybrid system consisting of: wind turbine model GE 1.5sl, a 4-kilowatt photovoltaic system and a 100 kg hydrogen tank. Furthermore, technical-economic assessment shows that establishment of hybrid plant in the area under study is confirmed.

The results illustrate the feasibility and effectiveness of implementing wind and solar energy for hydrogen production

1. Introduction

Excessive consumption of fossil fuels and the resulting environmental crises and the simple fact that these sources are far from unlimited highlight the necessity of finding limitless and yet clean alternative sources of energy [1]. Technology of solar and wind energies in recent years has progressed a lot and countries have often turned to one of these two energies in accordance with the position and potential of their region; So that in some regions of the world, a large percentage of the needed electricity supplied by the help of these energies [2]. On the other hand, in researchers' idea, lead-acid batteries are the most suitable option for short-term energy storage which cannot be used for long-term storage [3]. So, in the long term, by converting electrical energy into hydrogen by electrolyzer, it can be stored as fuel for fuel cells for future usage [4]. The high energy density of hydrogen has caused this element to be considered as a potentially reliable energy carrier. In addition, hydrogen is a clean fuel and this makes it extremely beneficial for achieving a sustainable environment [5]. The energy required for hydrogen production can be provided by traditional generators, nuclear reactors or renewable sources [6]. The use of alternative energy sources such as solar and wind power can be a good option for hydrogen production; but in addition to low energy efficiency and high cost, these systems are fully dependent on climatic conditions and this dependence complicates their design requirements [7]. The hybrid systems have been proposed to address this specific challenge, and have proven their potential as a viable alternative to traditional fossil fuel based power generation [8]. These systems employ two or more sources of renewable energy to achieve higher levels of efficiency and reliability than their rival systems [9]. So, hydrogen production, provides a suitable route for the generation of electricity based on wind energy and reduces the importance of fossil fuels in this field [10]. In recent years, hydrogen production through the use of hybrid systems (to provide the electricity required for water electrolysis) has been the subject of many researches [11]. According to these researches, in cases where hydrogen is produced by an electrolyzer, using a hybrid system with greater power output allows the design to incorporate an electrolyzer with greater hydrogen output [12].

This study consists of five parts. Firstly, previous researches have been stated in the literature reviews of this study. Then, geographical characteristics of the area under study, Materials and Methods of the study are analyzed and the conclusions are expressed in the last part.

2. Literature reviews

2.1. Various methods

Yilmaz et al. [13] investigated the methods of solar energy assisted hydrogen production. In that article, four methods of hydrogen

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production through photo-electrolysis, solar power, photo-biological generation and concentrated solar thermal energy and thermochemical process were studied. It was reported that PV-based hydrogen production still faces many challenges such as high costs of construction, repair and maintenance, and on before being used more extensively it needs to achieve higher levels of energy efficiency, safety and reliability. The results also showed that solar based energy production methods need further research aimed at increased efficiency and lowered costs.

Belmili et al. [14] provided a sizing method for designing a standalone PV-wind hybrid system, and then developed a software to evaluate the proposed system. In this study, all parameters affecting the system performance were analyzed by the use of an algorithm developed for this purpose. The techno-economic algorithm developed in this article was aimed at sizing the stand-alone PV-Wind system, determining the optimal size of battery bank and PV array for a given load, increasing the efficiency, and reducing the costs.

Chavez-Ramirez et al. [15] have presented a single-mode hybrid system of wind-photovoltaic fuel cells for using in University of Zacatecas aiming to produce energy and to produce hydrogen for converting into energy by fuel cell. Castaneda et al. [16] have presented a single-mode wind-photovoltaic-hydrogen hybrid system to optimize sizing, dynamic modeling and power management using dynamic simulations in MATLAB software. Chavez-Ramirez et al. [17] presented a hybrid system of solar-wind-hydrogen by Artificial intelligence (AI) for distant houses in Mexico. Valdez et al. [18] presented operational simulations of wind power plants in production network to produce hydrogen. Sanchez et al. [19] presented a hybrid system of new energies including wind-photovoltaic and hydrogen for rural areas located in the South East of Mexico and examined its technical-economic feasibility using optimizing techniques of artificial intelligence. Maleki and Askarzadeh [20] offered a hydrogen production system based on hybrid system of wind-photovoltaic using algorithms PSO, TS, SA and (particle swarm optimization (PSO), Tabu search (TS), simulated annealing (SA), and harmony search (HS)); sizing (sizing).

Petrakopoulou [21] by used a dynamic simulation of wind-solar power plant assessed the energy storage and hydrogen production on an island in Greece. Valved et al. [22] presented conceptual analysis of operating modes in energy saving plants using Key Performance Indicator (KPI) method with regard to storage of produced hydrogen in hybrid plants' cycle. Dincer and Acar [23] studied nineteen different methods of hydrogen production in terms of their effect on global warming, the cost of production, energy efficiency, and social cost of carbon, and reported that the highest efficiency is observed in fossil fuel reforming (83%) while the lowest efficiency is observed in solar based hydrogen production (2%). In a study by Joshi et al. [24], various methods of energy production were investigated and the performance of solar thermal and PV based hydrogen production techniques were evaluated. According to the results of this study, the solar thermal systems has a higher exergy efficiency than PV system. It was reported that in the solar thermal system, the main parameters of system efficiency is the efficiency of concentrating collector, and in the PV system, intensity of solar radiation and ambient temperature both affect the exergy efficiency of the system.

Yang et al. [25] investigated a thermal-electrical hybrid system consisting of a photovoltaic-driven alkaline water electrolyzer designed for hydrogen production. According to the results of this study, to improve the efficiency of hydrogen production, in addition to improvement of relationship between the electrolyzer and PV-array, the operating system of alkaline water electrolyzer, solar irradiance, and bang-gap energy should also be optimized. Yuksel and Ozturk [26] studied geothermal energy resources to produce hydrogen by proton exchange membrane (PEM) electrolyzer. The analysis was conducted by Engineering Equation Solver (EES) software. According to the results, the increase of geothermal water temperature from 130 °C to 200 °C improves the electricity production from 4 MW to 8.5 MW. Higher amount of power electricity leads to increase hydrogen production from 0.030 kg^{-1} to 0.075 kg^{-1}. Khalid et al. [27] designed a renewable energy system to provide electricity for a residential sector in Oshawa. According to results of this work, the proposed energy system had a 26.0% energy efficiency and 26.8% exergy efficiency and was able to produce 1523 kg/yr of hydrogen. Akyuz et al. [28] studied the intensity of solar radiation as one of the factors affecting the performance of photovoltaic systems. In this study, a test case in Turkey was selected and its hydrogen production was examined according to the irradiance intensity recorded over a year. According to this study, one of the factors influencing the efficiency of hydrogen production probability distribution is the factor of time. The maximum hydrogen production was reported to be between 600 and 650 W/m^2, the overall energy efficiency was 8.1%, and the average energy efficiency of the studied PEM electrolysis system was found to be 60.5% with 0.48 A/cm^2 current density. In the end, the cost of hydrogen production in Balikesir region, Turkey was estimated to $ 43.9 per kilogram of hydrogen.

Laoun et al. [29] analyzed a solar PV system for hydrogen production and investigated impact of each components on overall process. Bhattacharyya et al. [30] studied PV-hydrogen production under different environmental conditions. Results showed that different solar radiation leads to different amount of hydrogen production. According to the predictions, for producing of 10 $N\,m^3\,h^{-1}$, at 70 C and 5 bar pressure, 60 kW electricity is required. The experimental results showed the PV cells are able to produce 10.5 $N\,m^3\,h^{-1}$ that are 5% higher than predicted results. Abusoglu et al. [31] developed five different models including alkaline, PEM, high temperature water electrolysis, alkaline hydrogen sulfide electrolysis and dark fermentation biohydrogen to evaluate hydrogen production. Numerical analysis showed hydrogen production of the five models are able to produce 594, 625.4, 868.6, 10.8 and 56.74 kg respectively.

Liu et al. [32] presented the design of a new approach for polymer electrolyte membrane (PEM) fuel cell air-feed systems. They also used a modified super-twisting (ST) sliding mode. The new designed system is capable of estimating the system states, and fault signals too. The validation and effectiveness of the models was verified too. Liu et al. [33] proposed an extended state observer (ESO) based second-order sliding-mode (SOSM) control for three-phase two-level grid-connected power converters. Their idea is capable of tracking the desired values for regulating the output voltage while achieving a user-defined power factor. They also validated their results. Romero-Cadaval et al. [34] illustrated a general view of real solutions for applications of the PV energy systems. They investigated several main issues, including the most reliable models used for simulation. They also discussed main topologies for PV processing, and grid connection issues. Kouro et al. [35] illustrated an overview of recent research and emerging PV converter technology. They also addressed configuration system of PV plants and convertors for a system which is connected to the grid. Laghrouche et al. [36] presented an observation based method for PEM fuel cells. They also developed an adaptive-gain second-order sliding mode (SOSM) observer. It was concluded that the proposed model was feasible and effective.

2.2. Economic analysis

Mahesh and Singh Sandhu [37] performed a systematic study on a hybrid system consisting of wind and PV component and a battery storage. To achieve this end, these authors studied the modeling, economic analysis and viability, and reliability of this hybrid system, as well as different size optimization techniques, including analytic, iterative and artificial intelligence. According to the results of these investigations, artificial intelligence techniques such as GA, PSO and ACO reduce the computational burden of acquiring a globally optimal solution.

Al Busaidi et al. [38] studied the hybrid renewable electricity generation systems by investigating and sizing their different compo-