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# A comprehensive evaluation of hydrogen production from photovoltaic power station

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ABSTRACT

This paper presents the viability of hydrogen production through electrolysis process supported by a photovoltaic power system. To achieve this goal, economic feasibility and annual performance of 20 kW photovoltaic power station located in Yazd City in Iran is assessed though both experimental study and simulation. The data pertaining to real and simulated power output for the period of July 2012 to the end of June 2013 were compared and evaluated using the reference cell component of PVsyst simulation software. The real and simulated power output of the station is then used to assess its potential for PV-hydrogen production. Efficiency of the electrolyzer is considered to be 90% with power consumption of 5 KWh/Nm$^3$. According to the results, over the period of one year, panels receive 299.376 MW/h of solar radiation on their surface, and they manage to convert 12.32% (36.91 MWh) of the incoming solar radiation into electricity with the highest output in August and the lowest in December. Simulation of the power station shows that overshadowing effect reduces the output of power station by about 5%. It was also found that applying the monthly optimal angles instead of annual optimal angles on panels increases the power output by 6.83% without considering the overshadowing effect, and by 3% while considering that effect. After assessing the real and simulated power output of the station, the potential of PV-hydrogen production is estimated to be 373 t per year (actual production) with the highest output being in August. Results show that the region is capable of generating electricity for hydrogen production.

## 1. Introduction

The growing use of fossil fuels and the emergence of several problems have drawn the attentions toward the more extensive and efficient production and use of clean energy [1]. Generally, the most part of total energy consumption is related to the non-renewable energy sources such as gas, oil coal that leads to various economic, politic and environmental problems [2]. As a result, recent years have been witness to growing interest in hydrogen as an efficient and clean source of energy, this new source of energy can be a key solution to decrease negative environmental impacts of fossil fuel consumption [3]. Currently, the main applications of $H_2$ include the production of ammonia, soil enrichment, and production of methanol and other such chemical compounds, but it is also finding growing use as a clean energy source [4].

Sunlight is an important clean and environmentally friendly source of energy, and the amount of energy that reaches the earth through sunlight is much greater than all energy needs of humans [5]. Meanwhile, the issue of global warming and the greater affordability of new PV systems as compared with traditional ones have encouraged the further use of PV cells for more extensive production of clean energy [6]. Although there have been much progress in efficiency of PV cells and they are now about 29% efficient, the efficiency of these cells in commercial applications is still in the range of 10–20%; thus they cannot fully challenge the fossil-fuel made electricity [7]. Efficiency of PV cells can be influenced by various factors such as temperature and shadow, so forecast and estimation of system efficiency under realistic assumptions for weather conditions is of utmost importance [8]. In the case of this study, an accurate estimation allows us to obtain an accurate estimate of the cost and the output of hydrogen production through electrolysis.

In a research conducted in India, PV system were compared with the diesel system and the results showed that when solar irradiance is greater than 4 kW/m$^2$ the feasibility threshold of PV system is 53 kWh, and when solar irradiance is greater than 6 kW/m$^2$ that threshold is 77 kWh [9]. A study conducted on off-grid photovoltaic systems in Bangladesh has reported that in this country the cost of photovoltaic systems is lower than gasoline or diesel ones, so the use of these systems

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in rural and remote areas of the country is cost-effective [10]. A study in Kuwait has reported that the use of a 1000 mw photovoltaic systems can reduce the peak energy consumption by about 20%, as for each 1 mw produced by this system, the monthly average peak consumption reduce by about 0.76 mw. In addition, it was found that a 1000 mw system can reduce the Kuwait's annual energy consumption by about 15% [11].

There are three methods for generating hydrogen from water, including thermal chemical process (thermolysis), electrochemical process (electrolysis) and photochemical process (photocatalysis) [12], and four industrial processes which are oil Processing, natural gas, coal gasification and electrolysis [13]. In the electrolysis, the electrical energy is used to separate hydrogen molecules from water molecules. PV-Hydrogen is one of the most common technology to produce hydrogen by electricity power gained from PV cells. In this method, a PV power plant is account for electricity production for electrolyzing process of water. Using a PV power plant system with higher performance leads to increase of electrolyzer potential to produce hydrogen [14,15]. Using PV power plant to produce hydrogen is clean and environmentally friendly method. Therefore, hydrogen production systems operating based on solar energy (such as PV) have been the subject of extensive research [16]. Fig. 1 shows the diagram of the wind-hydrogen plant.

Many studies have been carried out using PV cells to produce hydrogen from water. Huang et al. [18] used a PV cell-wind turbine hybrid system to produce the electricity power for hydrogen production. It was concluded that two scenarios lead to increased efficiency of hydrogen production system: a) when 12 mw of power is supplied by the wind turbine and the remaining 18 mw is supplied by the PV cell. b) When the temperature of the electrolyzer reaches to 60 °C which improves the system performance by 0.1% as compared to temperature of 40 °C. Tebibel et al. [19] carried out hydrogen production by methanol electrolysis process(MPE) using PV cells to achieve high system performance and safe operation in Algiers. Results showed that methanol electrolysis process (MPE) with 24.38 g/m$^3$ hydrogen production has higher performance rather than water electrolysis process (WPE) with 22.36 g/m$^3$ when using horizontal and tilted PV array. Nikolaidis and Poullikkas [20] reviewed and compared 14 different production methods to produce hydrogen fuel. It was concluded that the biological process can be the most appropriate method to produce hydrogen. Moreover, the high investment rate for hydrogen production from water electrolysis, is the major barrier to increase the use of this method. Al-Sharafi et al. [21] studied the potential of PV cells and wind turbine to produce hydrogen. It was found that the integration of 2 kw PV array, 3 wind turbines, 2 kw convertor and 7 batteries storage bank is the most efficient configuration to produce hydrogen. Sellami and Loudiyi [22] conducted an experimental study about hydrogen production using PV cell. It was concluded that potassium hydroxide(KOH 3 M) with 5122 m$^3$ has higher performance rather than sodium hydroxide (NaOH 3 M) with 3279 m$^3$ under the same pressure, temperature and voltage. Qolipour et al. [23]employed Homer software to analyze feasibility of PV-wind power plant to produce hydrogen in Hendijan area in Iran. Results showed that the power plant has a annual potential to produce 3,153,762 kwh electricity and 31,680 kg of hydrogen over.

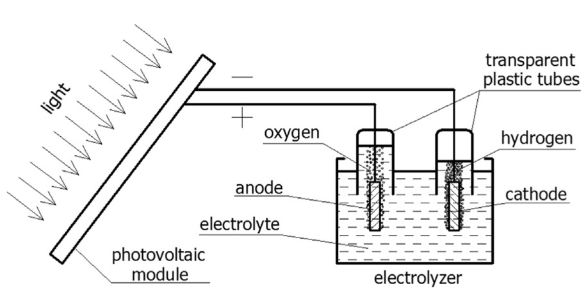


**Fig. 1.** Schematic diagram of hydrogen production with PV cell [17].

Dincer and Canan [24] have evaluated 19 different methods of hydrogen production in terms of their environmental impacts, price, and energy and exergy efficiency. According to this study, although hydrogen production by fossil fuels has the highest efficiency (83%) and lowest cost, it has the most devastating impacts on the environment, and in contrast, PV-based hydrogen production leaves the lowest environmental impact. Ghribi et al. [25] have studied the feasibility of hydrogen production through PV system in Algeria. The system assessed in this study is composed of 60 W PV modules connected to a 50 W (PEM) electrolyzer, and reported that considering the quality of sunlight, the use of PV-based hydrogen production has more potential in the South (29 m$^3$/year) than the North (20 m$^3$/year). The presence of better water resources in the southern parts of that country was also mentioned as an advantage of that area for hydrogen production through electrolysis process. Posso et al. [26] have studied the potential of renewable energy assisted hydrogen production including in different provinces of Ecuador. The energy sources assessed in this study include solar (photovoltaic), wind, geothermal and hydropower. The total amount of hydrogen production potential was reported to be 4.55 $\times$ 10$^8$ kg/year with the largest share belonging to PV cells. It was also stated that promotion of hydrogen fuel consumption in that country can lead to reduced import of fossil fuels, less environmental impacts, and increased welfare of poor people. Hosseini and Abdul Wahid [27] review renewable energy sources to produce hydrogen energy. It was found the low performance of PV cells to produce electricity power and high investment cost are two major barriers for PV-hydrogen production. Ma et al. [28] reviewed the impact of molybdenum carbide in electrolyzer performance in hydrogen production. It was found that this material can be an alternative catalyst with high performance.

Dahbi et al. [29] have combined the DC/DC converter and a water flow controller to increase the amount of hydrogen output of PV-electrolysis method. This study found that the use of DC/DC convertor leads to increased electricity output of PV system and its better coordination with electrolysis. Overall, controlling the system's water inflow by a water flow controller was found to increase the amount of hydrogen output. Bicer et al. [30] have used a solar simulator to evaluate the impact of different wavelengths of sunlight on the efficiency of photovoltaic cells and hydrogen production system. These authors have reported that the use of reflection mirror reduces the amount of solar irradiation by 17%, which in turn decreases the power output of PV system by 30%. It was also reported that due to higher energy capacity of lower wavelengths, more focus on these wavelengths can increase the efficiency of PV and electrolyzer. Erden et al. [31] have studied the possibility of using a hybrid system composed of solar pond, flat-plat collectors and organic Rankine cycle for producing hydrogen through electrolysis. This study has reported that combining the solar pond with flat-plate collectors increases the system temperature and leads to grater electricity output. This system can produce 2.25 kg of hydrogen per day, and its highest output in the morning hours, when the incident radiation is Maximum.

In the present paper, the information concerning an on-grid photovoltaic power station consisting of 84 poly-crystalline panels was collected and analyzed. This power station was also simulated and analyzed in the PVSyst software. The main goal of this work is to analyze the potential of hydrogen production using PV power plant in Yazd city. Moreover, the economic feasibility of construction, operation and maintenance of the PV power station was evaluated. The rest of this paper is organized as follows: In Section 2 the method and material is presented; Section 3 describes geological characteristic of Yazd city. The case study is presented in Section 4, and results are discussed in Section 5. Economic evaluation and hydrogen production are presented in Section 6 and Section 7, respectably. Finally, the conclusion is drawn in Section 8.