Feasibility of using a hybrid Photovoltaic-Wind Power Plant to Produce Hydrogen for Hendijan in the Southwest of Iran

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Abstract

The present study investigates feasibility of establishing hybrid photovoltaic-wind power plant to generate electricity and then hydrogen using Homer software for city of Hendijan in the Southwest of Iran. The findings shows that the city is capable of generating 3153762 kWh of electricity for a Photovoltaic-wind power hybrid system annually, and then produce 31680 kg of hydrogen for constructing a hybrid system consisting of: wind turbine of GE 1.5sl model, a 4-kilowatt photovoltaic system, and a 100 kg hydrogen tank. It is concluded that establishment of hybrid plant in this location is economically feasible.

Keywords
Photovoltaic-Wind power plant; Hydrogen production; Techno-Economic Feasibility; Homer; Hendijan.

1. Introduction

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 (Garcia-Heller and Paredes, 2016). 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 (Solomon et al., 2016). 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 (Giuseppe Mura et al., 2015). 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 (Ehteshami et al., 2016). The energy required for hydrogen production can be provided by traditional generators, nuclear reactors or renewable sources (Boudries et al., 2014). 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 (Sinha and Chandel, 2015). 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 (Maatallah et al., 2016). These systems employ two or more sources of renewable energy to achieve higher levels of efficiency and reliability than their rival systems (Siddaiah and Saini, 2016). 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 (Petrakopoulou et al., 2016). 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 (Abdin et al., 2015). 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 (Gen et al., 2012).

Mahesh and Singh Sandhu (2105) 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. Yilmaz et al. (2016) investigated the methods of solar energy assisted hydrogen production. In that article, four methods of hydrogen production through photoelectrolysis, 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. Rezk and Dousky (2016) studied the feasibility of a standalone hybrid system consisting of PV, wind and fuel cell renewable energy systems. To achieve this goal, these authors examined six different configurations in order to find the most efficient way to produce electricity for agricultural irrigation in Minya Governate, Egypt. Result of these examinations showed that the PV systems consisting of photovoltaic cells, fuel cell, electrolyzer, water pump and hydrogen tank has the highest efficiency and lowest cost among studied methods. Khare et al. (2016) reviewed various aspects of hybrid renewable energy generation systems and studied the prefeasibility analysis, optimum sizing, modeling, control methods and reliability issues of these systems. In the end, these authors investigated the applications of evolutionary technique and game theory in renewable hybrid systems. Hosseinalizadeh et al. [17] studied the feasibility of a hybrid renewable energy system consisting of wind turbines, PV and fuel cells for four regions of Iran using the data pertaining to solar radiation and average wind speeds. According to the results of this study, hybrid systems consisting of wind turbines and photovoltaic cells impose lower costs than PV-Turbine systems. In addition, the PV system was found to have a better energy efficiency than the wind turbine system. In the end, the Moaleman region was found to have the lowest energy cost (0.54 $/kWh) among studied regions. Al Busaidi et al. (2016) studied the hybrid renewable electricity generation systems by investigating and sizing their different components with respect to economic, environmental, and efficiency criteria. After analysis and comparison of two case studies in Oman, the energy costs of PV-Wind solar hybrid system located in Masirah and the hybrid system located in Halaniyar were found to be 0.182 $/kWh and 0.222 $/kWh respectively. According to the results of this research, these cities have a high potential for the use of solar-wind energy. Belmili et al. (2014) 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. Rahman et al. (2012) checked the feasibility of a wind-photovoltaic-diesel hybrid system in a village of Saudi Arabia. Ebid et al. (2015) offered an Economic analysis of a Hybrid power plant from photovoltaic-hydrogen and gas turbines with a capacity of 100 megawatts of produced electricity. Petrakopolo et al. (2016) using a dynamic simulation of wind-solar power plant assessed the energy storage and hydrogen production on an island in Greece. As is clear from the above-mentioned researches, there is no research that study technical-economic feasibility of a hybrid photovoltaic-wind-hydrogen power plant with regard to network connectivity using Homer software.

There are different works showing that implementing clean sources are possible in many different parts of Iran (Alavi et al., 2016a; Alavi et al., 2016b; Alavi et al., 2016c; Ezzabadi et al., 2015; Fereidooni et al., 2018; Goudarzi and Mostafaeipour, 2017; Minaeian et al., 2017; Mostafaeipour and Abessi, 2010; Mostafaeipour et al., 2016a; Mostafaeipour et al., 2016b; Mostafaeipour et al., 2014; Mostafaeipour et al., 2017; Mohammadi et al., 2016a; Mohammadi et al., 2016b; Qolipour et al., 2016; Qolipour et al., 2017; Ramezankhani et al, 2016; Sedaghat et al., 2017; Zarezade and Mostafaeipour, 2016).

Therefore, this is a research gap from previous researches and in this study it has been tried to assess the possibility of establishing a renewable energy hybrid plant aiming at producing hydrogen in an area of the South West of Iran, using Technical-economic feasibility through Homer software.

2. Geographic characteristics

Hendijan is a county in Khuzestan Province in Iran that it located in 30°14′11″N and 49°42′43″ E of latitude and longitude ordinarily. The capital of the county is Hendijan. It is located in the west-south of Iran that is connected to Persian Gulf through Zohreh River. At the 2014 census, the county's population was 64,374, in 8,437 families. The county is subdivided into two districts: the Central District and Cham Khalaf-e Isa District. The county has two cities: Hendijan and Zahreh (Federal Research Division, 2004). Figure 1 shows the location of Hendijan.

Figure 1. Map of Iran including Hendijan area

3. Methodology

3.1. HOMER software

The HOMER Software is Energy Modeling Software for Hybrid Renewable Energy Systems. The HOMER energy modeling software is a powerful tool for designing, Simulating and analyzing hybrid power systems, which contain a mix of conventional generators, combined heat and power, wind turbines, solar photovoltaic, batteries, fuel cells, hydropower, biomass and other inputs. It is currently used all over the world by tens of thousands of people. For either grid-tied or off-grid environments, HOMER helps determine how variable resources such as wind and solar can be optimally integrated into hybrid systems. Engineers and non-professionals alike use HOMER to run simulations of different energy systems, compare the results and get a realistic projection of their capital and operating expenses. HOMER determines the economic feasibility of a hybrid energy system, optimizes the system design and allows users to really understand how hybrid renewable systems work. As distributed generation and renewable power projects continue to be the fastest growing segment of the energy industry, HOMER can serve utilities, telecoms, systems integrators, and many other types of project developers - to mitigate the financial risk of their hybrid power projects. In addition, HOMER Energy site provides software, services, and an on-line community to the diverse group of people who are using HOMER to design hybrid systems (Mostafaeipour et al., 2016a; Qolipour et al., 2016). Research procedure is as follows:

1. Data Collection for performing the data processing by Homer software, including solar energy, wind energy and hydrogen production system data
2. Importing data from all three types of renewable energy in Homer software and processing them by the software
3. Extraction of Homer software’s technical and economic outputs for each of the three types of photovoltaic, wind and hydrogen systems
4. Technical analysis of all three types of energy
5. Analysis of the integrated technical and economic findings of simulated hybrid power plant

6. Presentation of research results

Homer software's inputs and outputs along with analysis of research findings can be found below.

4. Analysis

The Homer software was used for technical-economic feasibility of wind-solar-hydrogen hybrid system. Initially, the data related to wind speed for the Hendijan area was extracted using Iran's weather forecasting website in monthly form from 2000 to 2014 and was entered to the Homer software. Then, Information necessary to evaluate the solar potential in the area including air filter indicator and daily radiation were obtained using geographical coordinates of Hendijan area. Homer's website was used to download input data for the hydrogen system and reputable websites such as "Alibaba (Alibaba)" as reference of price of any of the equipment used in hybrid systems. Simulation processes and sensitivity analysis were carried out on data at the time of 2:36 (two minutes and thirty-six seconds) on the 7200 simulations after entering information for each of the three types of the energy. Equipment used in the Wind-Solar-hydrogen hybrid system are: a GE 1.5sl turbine, a 4-kilowatt generator, a 4 kW converter, a 4 kW photovoltaic system, a 100 kg hydrogen tank, a 20 kg reformer and 1000 kW electricity grid for a period of 25 years. The Profiles of feasible hybrid system have been shown in Table 1.

Table 1. Techno and financial specification of the power plant

Specification	Equipment and Indexes					
System architecture	Grid	Wind turbine	PV	Generator	Inverter/Rectifier	Reformer
	1000 kw	GE 1.5sl	4 kw	4 kw	4 kw/4 kw	20 kg/yr.
Financial	Capital	O&M	Fuel	Total NPC	Levelized COE[1]	Operating
	706,200	696,315	86,902	97,012	0.572 $/kwh	-111,432 $/yr.
Electrical production	PV array	Wind turbine	Generator	AC primary load	Grid sales	Excess electricity
	9,437	3,137,977	6,348	31,025	2,764,118	358,297
Grid	Energy	Energy	Net	Peak	Energy	Demand
	Purchased	Sold	Purchased	Demand	Charge	Charge
	435 kwh/yr.	2,764,118 kwh/yr.	-2,763,683 kwh/yr.	6 kw/yr.	-138,119 $/yr.	119 $/yr.
Hydrogen system	Reformer production	Hydrogen production	Levelized COH[2]	Capacity factor	Unmet hydrogen load	Electrolyzer production
	32.010 kg/d	88 kg/d	-16.9 $/kg	0.183	370 kg/yr.	0.00 kg/yr.
Pollution (kg/yr.)	CO_2	CO	Unburned hydrocarbons	Particular matter	Sulfur dioxide	Nitrogen oxides

Now, outputs obtained from the Homer software are separately provided and analyzed for wind, solar and hydrogen systems.

4.1. Techno-Economical analysis of Wind potential

Wind energy potential of the study area is obtained in form of generated power and its economic equivalent using wind speed and technical-economic feasibility of proposed wind turbine outputs through the Homer software. Figure 2 shows the diagram of wind speed's monthly average for the study area in different months. According to Figure 2, the lowest wind speed is in November with 3.72 meters per second and the highest wind speed is in June with 3.72 meters per second.

[1] Cost Of Energy
[2] Cost Of Hydrogen

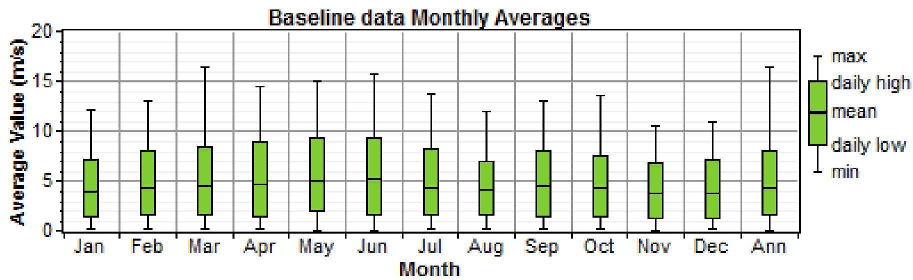

Figure 2. Wind speed profile in the study area at difference month

4.2. Techno-Economical analysis of solar potential

The geographical coordinates of the study area including longitude and latitude were entered into the Homer software in the feasibility of solar energy potential of Hendijan area for hybrid power plant construction and air filter and daily radiation indexes were downloaded from Homer's site. Information of which, have been shown in Figure 3.

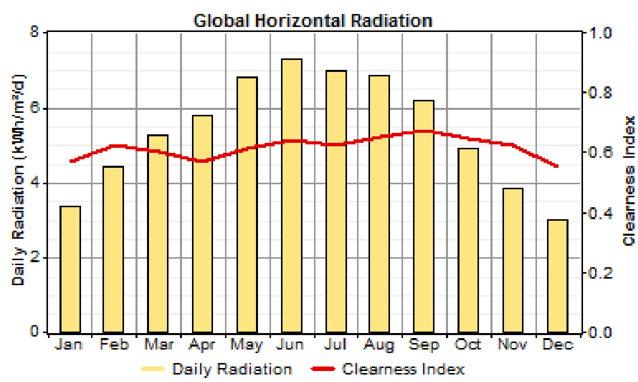

Figure 3. Diagram of Daily Radiation & Clearness Index for the case study

Figure 4 shows the monthly average of air filter index in different months of the year. The status of air filter index in the study area can be understood better using Figure 4.

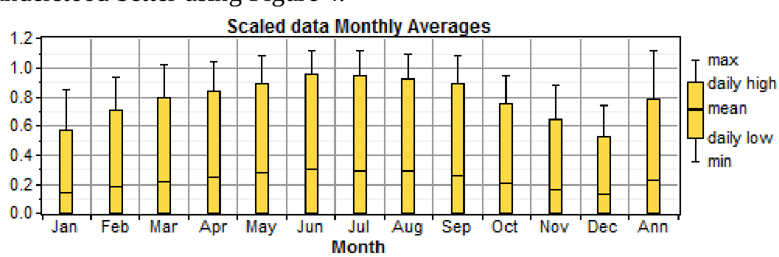

Figure 4. Scald data monthly average of clearness index for the case study

Selecting the appropriate solar Panel and evaluating the output of a photovoltaic system are among important measures in a photovoltaic system. Selecting the type of solar panel is done by Homer software after simulation and technical-economic feasibility.

4.3. Analysis of Hydrogen potential

Technical-economic feasibility of the hydrogen system in the present study is one of the innovations of the present study. This research has tried to provide a technical-economic feasibility and evaluation of a new power generation system with hybrid from wind, solar and hydrogen energy.

Figure 5 shows the monthly average of produced hydrogen. According to Figure 5, January has the highest amount of hydrogen production with 126 kg of hydrogen per day. February has the lowest amount among the different months with 76 kilograms of produced hydrogen per day.

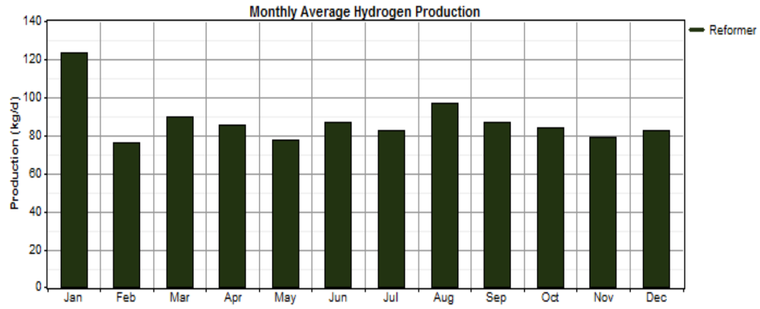

Figure 5. Monthly average Hydrogen production

We will now carry out the total technical-economic feasibility of the proposed wind-solar-hydrogen system

4.4. System analysis for suggested power plant

The new energy proposed system for the District of Hendijan is a hybrid system of wind, solar and hydrogen. Monthly averages of sold electricity along with annual average have been shown in Figure 6. According to Figure 6, the maximum monthly sales equal to 900 kW are in June and July and the minimum monthly sales equal to 700 kW are in November.

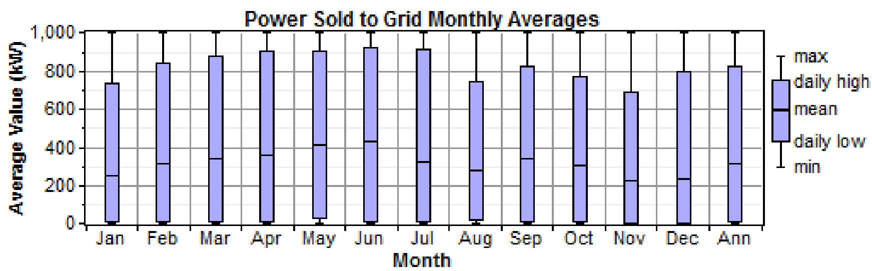

Figure 6. Power sold to Grid monthly averages

Monthly average of electricity production from the proposed hybrid system has been shown in Figure 7. According to Figure 7, the largest share of electricity production belongs to wind turbines and the output of other hybrid production System components such as photovoltaic system and generator are insignificant in comparison with turbines. The highest monthly average of the electricity produced was in June and the lowest was in November.

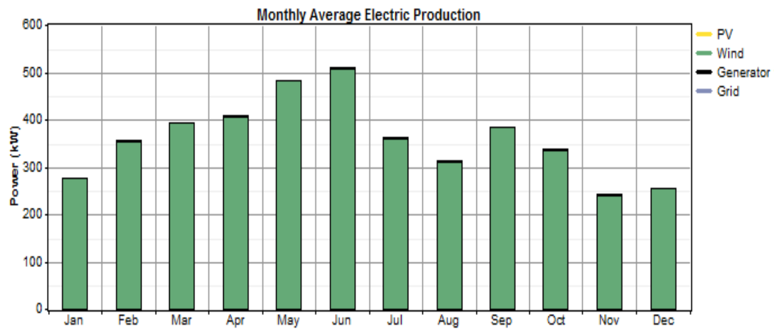

Figure 7. Monthly average electric production

There is an additional amount of electrical energy produced aside from the amount of electricity sold by the distribution network for simulated system which surplus on grid sale and consumption. Figure 8 shows the diagram related to monthly average grid surplus of electricity production. According to Figure 8, June had the maximum amount of surplus power with monthly average of 350 kilowatts and November and December had the minimum amount of surplus power with monthly average of 50 kilowatts.

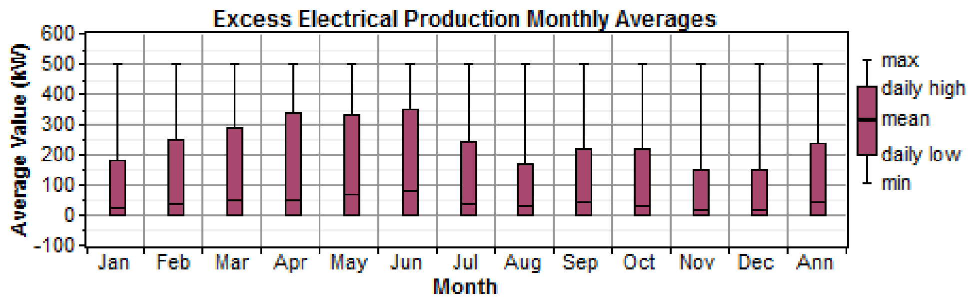

Figure 8. Excess electrical production monthly averages

After presenting the technical feasibility of the proposed hybrid system, it is time for the economic assessment. It has determined so far that the presented hybrid system is approved in technical terms (producing electricity and hydrogen) but economically, the amount of produced electricity by simulated system must be multiplied by the price of each kilowatt hour in order to calculate the annual income of wind-solar-hydrogen hybrid system. Figure 8 shows the summary of cash flow for simulated system for each of the components used in the system. The colored bars below the zero line are as the income of hybrid system and as a negative cost in order to calculate the total net cost for the system by deducting the cost of the system which includes: the cost of purchase, repair and replacement of equipment.

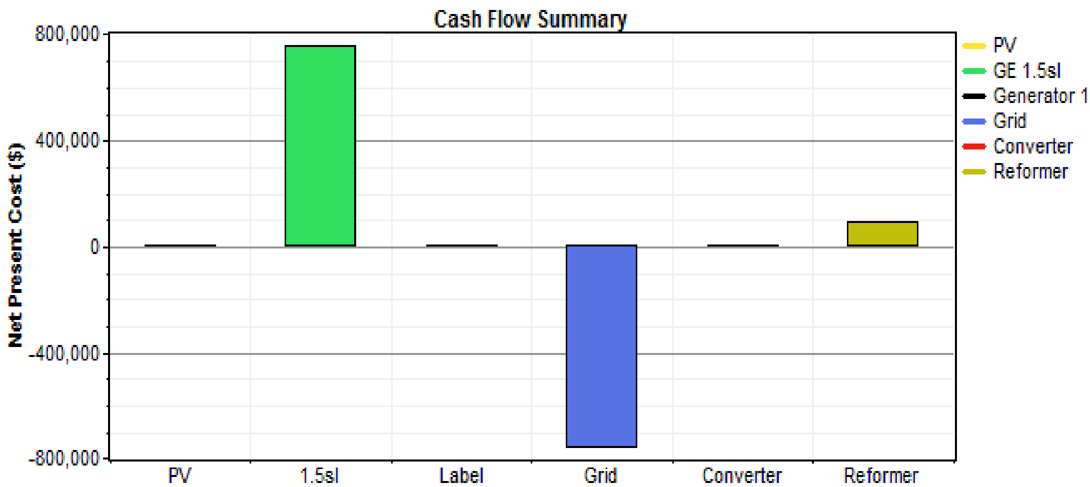

Figure 8. Cash flow summary of feasibility

According to Table 1, the electricity generated by power plants for a turbine, a 4-kilowatt generator and a photovoltaic system are respectively 3137977, 6348 and 9437 kWh per year. In addition, the 31 680 kg of hydrogen produced in the year is derived from it. Two important notes must be expressed for economic assessment of Hybrid power plants' construction project with proposed equipment:

1. Homer software performs feasibility test for only one turbine in large wind turbines (wind turbines with a capacity of more than 1.5 MW) and the operator can expand the system with the necessary number of turbines.
2. Economic feasibility is done for a wind turbine, a generator, a 4-kilowatt photovoltaic system and a hydrogen tank for economic assessment. Then proposed power plant would be consist of a several of these hybrid system.

The new Energy's price per kilowatt is initially required to be determined in order to calculate the income from the electricity produced by the hybrid system. The price of each kilowatt of electricity obtained from new forms of energy is 0.2 dollars (MOE site of Iran, 2016). So we have:

$$R = P_T \times V \tag{1}$$

That in it:

P_T; Electric production per year.

V; Price per 1kw electric production.

R; Net income per year (BCI site of Iran, 2016).

Then: $R = P_T \times V = 3153762 \times 0.2 = \$630752$

Thus, the average annual income of 630,752 dollar is obtained from renewable energy including photovoltaic and wind power for the mentioned hybrid system in the studied area. Meanwhile, 31680 kg of hydrogen per year is obtained from each described photovoltaic-wind hybrid system. Thus, hybrid PV-wind-hydrogen power plant construction in the Hendijan area is economically approved and since the proposal project has been approved in technical aspects, the hybrid power plant construction in the study area is a development opportunity for Renewable Energy.

5. Conclusion

Iran, despite its high potential in renewable and nonrenewable energy sources has not still been significantly evaluated in the field of energy. Assessing the capacity of producing hydrogen in different parts of Iran through wind power plants, photovoltaic or hybrid PV-wind power plants are among important matters which their absence can been seen previous researches. Therefore, this study has been carried out with the aim of feasibility of technical-economic wind-solar-hydrogen power plant using homer software in Hendijan area of Khuzestan province. Initially data on wind speed, air filter indicator, Daily radiation, and data related to the hydrogen system were collected for the studied area. Then, the collected data were entered into the Homer software and were processed. Processes of simulation and sensitivity analysis were performed on data at the time of 2:36 (two minutes and thirty-six seconds) on 7200 simulation. Equipment used in the Wind-Solar-hydrogen hybrid system were a GE 1.5sl turbine, a 4-kilowatt generator, a 4-kilowatt converter, a 4-kilowatt photovoltaic system, a 100 kg hydrogen tank, a 20 kg reformer and 1000 kW electricity grid for a period of 25 years. The results of software processing showed that the studied area has a great potential of renewable energy, especially wind power energy and hydrogen production. According to Homer software the amount of power output of the power plan for one turbine, a 4-kilowatt generator and a 4-kilowatt photovoltaic system were obtained to be respectively equal to: 3137977, 6348 and 9437 kW and 31680 kg of hydrogen were obtained per year. According to conducted technical and economic analysis, the cost of the hybrid system is 1600849 dollars and its annual income equal to 630752 dollars. Thus, it was confirmed that of hybrid PV-wind-hydrogen power plant construction in the Hendijan area is economic.

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