Placement of Solar-Wind Hybrid Power Plant in iran with using AHP algorithm and technical and economic evaluations by HOMER software

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Abstract

Due to the growing demand for energy and limited fossil energy resources, followed by increase in prices of fossil energy carriers, the need for using renewable energy is becoming even more tangible. Wind and solar energy are the most important types of renewable energy sources. In The paper, the weather maps were investigated based on wind regimes and solar radiation maps in different parts of the Hormozgan province in a period of 5 years from 2009 to 2013, and considering the effective parameters in choosing the location of wind solar plants, AHP algorithm was used to determine the best location for the construction of solar wind plants, and then The HOMER software was used to optimize and analyze the sensitivity of an off-grid Solar Wind Power Plant for a remote village in the city of Bandar Lengeh in Hormozgan province in iran. Power generation to meet peak electric charge demand of 217 KW and energy consumption of 3 MWh/d was simulated as off-grid power, and above from determination of the wind and solar energy contribution in the supply of the overall consumer electric charge, it was economically investigated as well.

Keywords: wind speed, solar radiation, NPC (Net present cost), AHP (analytic hierarchy process), COE (cost of energy), hybrid system, HOMER.

1. Introduction

Today, the increasing warming of the Earth's atmosphere due to the negative effects of greenhouse gases, is one of the most important and significant issues. The use of fossil fuels to fuel power plants, not only leads to their rapid run out, but causes the Environmental pollution to increase. So that, according to the estimates, for each MWh of energy produced by diesel fuel, the amount of 21.3 kg oxides, carbon monoxide as well as 675 kg carbon dioxide is released to the air [1]. Reduction of the fossil fuels has led to consideration of renewable energies such as wind, solar, geothermal, etc. as clean, endless, limitless and environmentally friendly sources of energy [8,11]. The advantage of Renewable energies (compared to fossil fuels) is that they are replaceable and available everywhere, moreover, they are basically non-polluting. The disadvantages of this energy include high density and low diversity, which due to the need for space occupation and storage or backup power, lead to high preliminary costs [15].

Increased use of renewable energy has led to economic growth, creation of job opportunities, improvement of national security, protection of consumers against rising prices, supply of fuel deficit on the global market and a significant reduction of the pollutants that cause greenhouse effects and global warming. Therefore, the issue which policymakers of the electricity market are faced with is how to use renewable energies in the energy market, so that these energies may appropriately play their role in the future market. The above-mentioned Specifications renewable energies has led to their large-scale consumption today. Wind power and solar energy are the most readily available sorts of renewable energies, but their dependence on the environment and climate is one of their problems. The combination of both energy sources can neutralize the weaknesses in each of them [13,2]. today, the hybrid power generation system has become one of the most promising solutions to meet the electricity needs of different regions. Ensuring the continuity of power supply by storing excess energy from renewable energy sources is one of the basic needs of the hybrid system [3]. In this paper, battery is used as an energy storage system. Hybrid energy systems based on these alternative technologies that can work in parallel with renewable resources, are a suitable solution for limited power generation [14].

In this paper, analytic hierarchy process (AHP) and Expert Choice software are used to determine an optimum location for construction of Solar Wind Hybrid Power Plant. Expert Choice software is designed for analysis of Multi-criteria decision-making problems multiple criteria using Analytical Hierarchy Process and can be run on personal computers. This software has many capabilities and in addition to designing hierarchical diagrams, is capable of designing and making decisions for questions for determining the preferences and priorities, calculating the final weight, as well as analyzing the decision-making sensitivity toward changes in the parameters of the problem. Above all, in many cases, this software uses charts and graphs for presentation of results and performances and makes a simple and friendly relation with users [7]. Moreover, HOMER software was used for simulation and and technicall and economical evaluation of the hybrid system. This software was developed and expanded by the National Renewable Energy Laboratory in the United States of America. The HOMER software allows users to compare different design options based on technical and economic issues. In the process of optimizing all the different arrangements of the power supply, with consideration of the constraints, attempts are made to achieve the most economical mode for the life cycle cost. The software is also able to perform sensitivity analysis on variables with unrealistic values.

2. Introduction of the study area

The Hormozgan province is one of Iran's 31 provinces which is located in the south and between geographical coordinates of 25 degrees and 30 minutes to 28 degrees and 53 minutes North latitude and 52 minutes and 44 degrees to 59 degrees and 16 minutes east longitude of the Greenwich meridian. This province occupies an area of about 72631.31 square kilometers and constitutes about 4.1 percent of the country. In general, Hormozgan has a desert climate, with long hot summers and short mild winters. The province's climate equilibrium is influenced by various air masses from north-west and south and is generally dry. Figure 1 shows the Map of the province divisions[4].

Fig 1. Map of the hormozgan province divisions

3. Wind and solar data

Given that this study required the solar and wind data over a period of 5 years, in this article, Bashagard County in the East, Bandar Abbas in the center and Khamir and Bandar Lengeh in the West of the Province were selected to be studied.

3.1 wind speed data

Wind speed data were collected at a height of 10 meters for four weather stations in Bashagard, Bandar Abbas, Khamir and Bandar Lengeh during a five-year period from 2009 to 2013, in m / s according to figures 2 to 5.

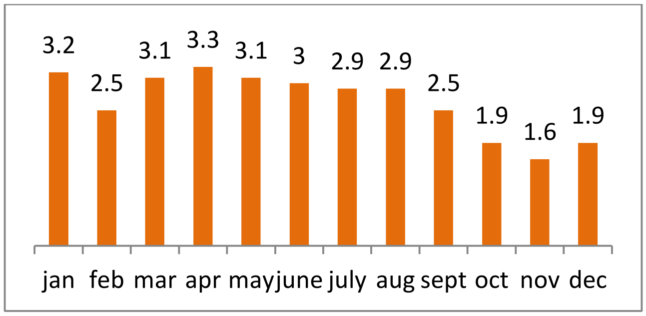


Fig 2. Monthly average of wind speed of Bashagard during a five-year period (in meters per second)

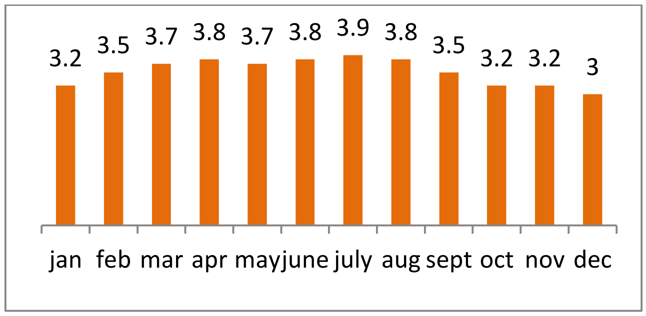


Fig 3. Monthly average of wind speed of Bandar Abbas during a five-year period (in meters per second)

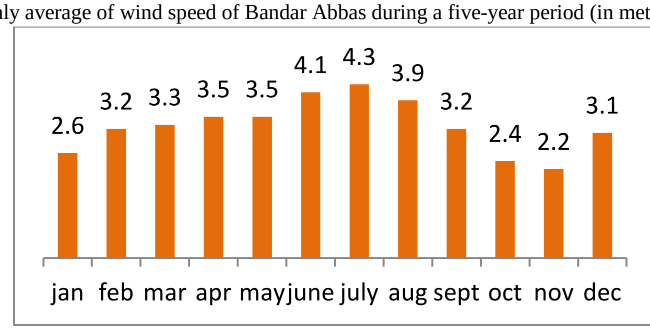


Fig 4. Monthly average of wind speed of Khamir during a five-year period (in meters per second)

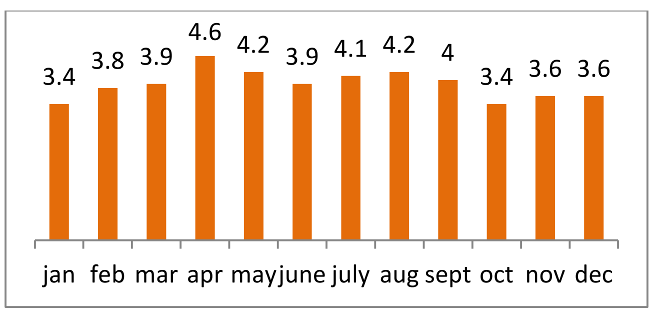


Fig 5. Monthly average of wind speed of Bandar Lengeh during a five-year period (in meters per second)

3.1 solar radiation data

Solar radiation data for four weather stations of Bashagard, Bandar Abbas, Khamir, and Bandar lengeh during a five-year period from 2009 to 2012 (w / m2) according to Figures 6 to 9.

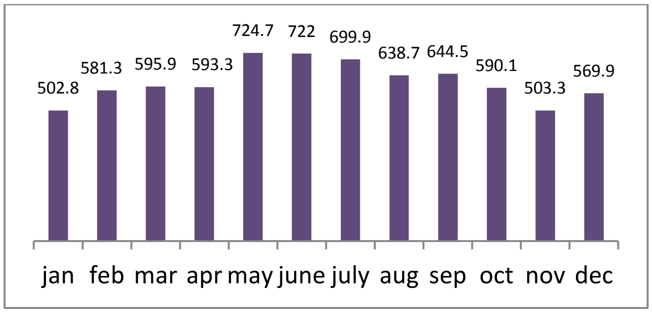


Figure 6. monthly average of solar radiation in Bashagard during a five-year period (w / m2)

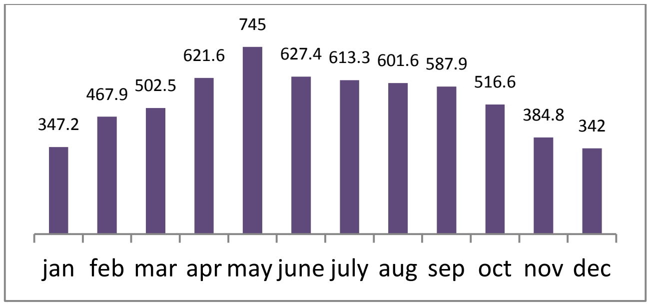


Figure 7. monthly average of solar radiation in Bandar Abbas during a five-year period w / m2

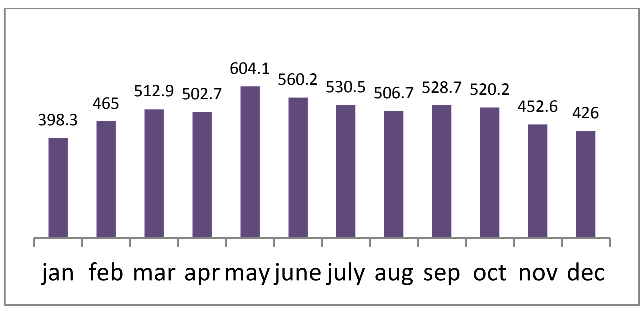


Figure 8. monthly average of solar radiation in Khamir during a five-year period (w / m2)

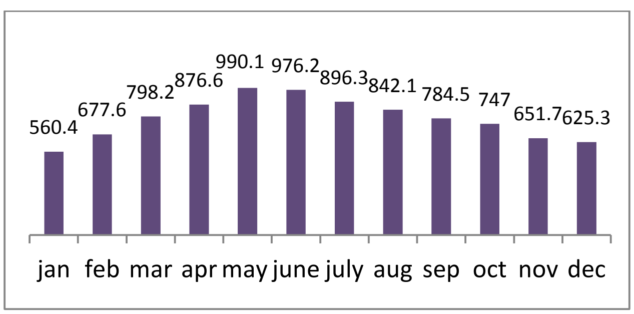


Figure 9. monthly average of solar radiation in Bandar Lengeh during a five-year period (w / m2)

4. Modeling the wind-solar hybrid power plant and determining the best location for that, using Ec software

This decision-making aimed to select the best location for wind solar hybrid power plant. The criteria include: Wind speed, solar radiation, Price of land, difficult transit zone and the lack of tall structures. And decision-making options included 4 regions named, Bashagard, Bandar Abbas, Bandar Lengeh, and Khamir. Figure 10 shows the numerical judgments between the criteria. After calculation of the relative weight of the criteria as well as the relative weight of options against each of the criteria, the software calculated the final weight of each option and rated the options in accordance with the aim of this decision-making. As seen in Figure 11, Bandar Lengeh with the final weight of 0.505 was selected as the best place for construction of the solar wind hybrid power plant. And then

Bashagard with the final weight of 0.215 , Bandar Abbas with the final weight of 0.161 and Khamir with final weight of 0.119 were the next priorities for construction of solar wind hybrid power plant.

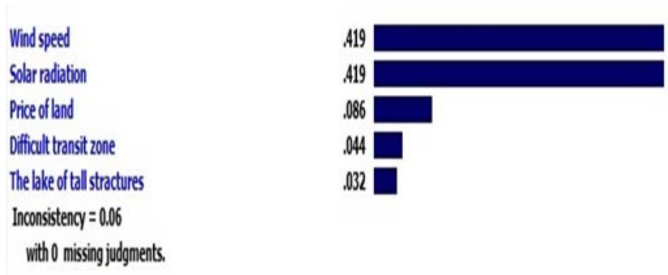


Figure 10. calculation of the relative weight of the criteria in the EC software

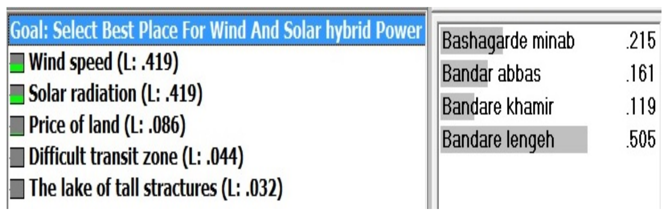


Figure 11. the final weight of the options in terms of the goal

5. Technical and economic evaluation by the HOMER software

In this section, the HOMER software is used to design and model a technically and economically optimized solar wind hybrid power plant in a remote and difficult transit zone in the county of Bandar Lengeh.

5-1 hybrid system

Basically a hybrid system is formed of renewable energy sources which work in parallel with the non-renewable energy source and an energy storage unit. The Hybrid system in this article is formed of wind and solar renewable energy sources and its components include wind turbines, photovoltaic arrays, batteries and an inverter. Figure 12 shows a model of the hybrid system in the HOMER software. Detailed information about the components of the hybrid system is presented in the following sections.

Figure 12. the model of a solar-wind hybrid system in the HOMER software

5-1-1 electrical load

The consumer electric charge of a mountainous, remote and difficult transit village (Brest) within 45 km from the center of Bandar Lengeh, was considered the off-grid electric charge. Consumption of electricity in this village was about 3 MWh / d and maximum electric charge demand was estimated about 217 kW. Figure 13 shows a single day’s electric consumption profile in this village. As shown in the figure, maximum electric charge and the minimum electric charge are 160 kW and 96 kW at 23 and 7 o’clock respectively.

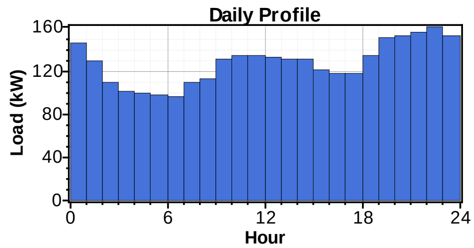


Figure 13. daily profile of power consumption in the village of Brest

5-1-2 wind and solar energy sources

Wind and solar energy are renewable energy sources that are considered for this study. The data used in this study were collected from the Meteorological station in this region, and the monthly average of wind speed and solar radiation for a period of five consecutive years (from 2009 to 2013) was used. The annual Average of wind speed in Bandar Lengeh is 3.89 meters per second. Figure 14 shows the monthly Average of wind speed for different months of the year.

Figure 14. average of wind speed in the region during different months of the year

Figure 15 shows the cumulative distribution function of wind speed. In these calculations, the weiboll distortion coefficient (the degree of wind distortion over a year) is 1.97 and the autocorrelation coefficient is 0.85 . Figure 16 shows the monthly Average of solar radiation data in the HOMER software .

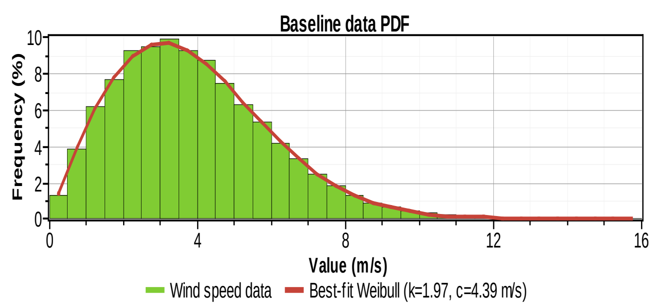


Figure 15. the cumulative distribution function of wind speed

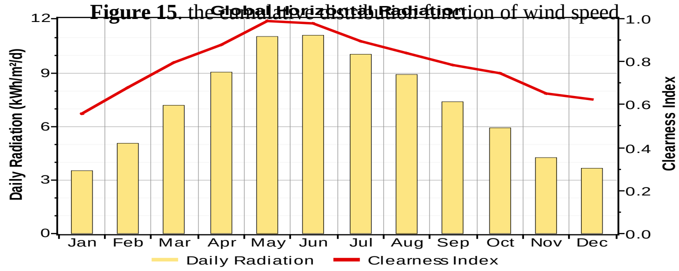


Figure 16. monthly Average of solar radiation in HOMER software

Annual Average of solar radiation in the Bandar Lengeh county is 6.93 kwh / m2 / d . The Red line in the figure is as an index that is referred to as transparency. Transparency index is the ratio of Earth's surface solar radiation to the ration of atmosphere solar radiation.

5-2 Components of the hybrid system

Hybrid system components include wind turbines, solar arrays, batteries and a power inverter. The specifications of each component and costs related to them should be fully and accurately inserted to the software. These components are described in the following sections.

5-2-1 wind turbine

Wind turbine power output is dependent on the changes in wind. A fuhrlaender wind turbine is used In this analysis. The nominal Power of this turbine is 100 kW and current used in that is an alternating current . The cost of each unit, as well as replacement and maintenance costs are: 100,000 $, 80,000 $ and 50 $ respectively.

Given that the data of wind speed are sampled at a height of ten meters and the turbine is installed at a height of 35 meters, the equation (1) is used in the Homer software to calculate the wind speed.

$$\boldsymbol{v_w^h} = \boldsymbol{v_w^{ref}} \times \left(\frac{\boldsymbol{h}}{\boldsymbol{h_{ref}}}\right)^{\propto} \qquad (1)$$

In equation (1), $\boldsymbol{v_w^h}$ shows the wind speed at a height of h, and $\boldsymbol{v_w^{ref}}$ shows wind speed at the measurement height of$\boldsymbol{v_w^{ref}}$, in meters per second. α is a typical value (1.7) [10].

5-2-2 solar array

Solar arrays without tracking system are used in this study and the Installation and replacement costs for the 1 kW system is considered 3000 $ and 2,500 $ respectively.

5-2-3 inverter

Establishment of the desired connection between AC input and DC output requires an electronic inverter. The installation, replacement and maintenance costs of a 1 KW system is considered 800 $, 750 $ and 10 $ respectively.

5-2-4 Battery

A battery of surrette 6cs25p, with specifications of 9645 kwh, 1156 ah and 6 **v** which can be studied in HOMER was used. The installation, replacement and maintenance costs per unit of battery was considered 500 $, 450 $ and 6 $, respectively.

5-3 analysis of Hybrid system and sensitivity

HOMER software used the net present cost (NPC) equation to calculate the life cycle of the system. The net present cost is defined as difference between the present value of all the necessary costs during the period of the project and the present value of the revenues resulting from that. All costs and revenues are assessed with a fixed interest rate during the year. in this assessment for examine effect of inflation on the calculations, the calculation of real interest rates due to inflation, the effect of interest rate changes on the net present cost The real interest rate is calculated according to equation (2). Where i denotes the nominal interest rate and f is the interest rate of inflation.

$$\mathbf{i} = \frac{\mathbf{i'-f}}{\mathbf{i+f}} \qquad (2)$$

The net present cost is the main output of economic calculations in this software, which is calculated through equation (3).

$$\boldsymbol{C_{NPC}} = \frac{\boldsymbol{C_{ann,tot}}}{\boldsymbol{CRF(i,R_{pro})}} \qquad (3)$$

$C_{ann,\ tot}$ is the total annual cost, Rpro is the period of the project, and i is the real rate of interest. CRF which is the investment return factor in N years, is defined by the following equation (4).

$$\boldsymbol{CRF(i,N)} = \frac{\boldsymbol{i(1+i)N}}{\boldsymbol{(1+i)N-1}} \qquad (4)$$

Another important factor in the economic calculations of the distributed generation units, and optimum combination selection which is calculated by HOMER, is the average cost of a kilowatt-hour useful energy (COE) generated by the system. In the course of optimization, the best combination is selected from among different arrangements. The best combination may be a combination that fulfills all the requirements determined by the operator with the lowest net present cost. HOMER simulates the possible scenarios and then arrange them based on the lowest net present cost, finally the arrangement which is realizable with the lowest net present cost, is presented as the optimal arrangement.

5-3-1 simulation and analysis of the hybrid system

Figure 21 shows the optimization results. As you can see, the possible combinations for the system are arranged in terms of increasing net present cost (NPC). Therefore, to supply the electric power of Brest village with a maximum electric charge demand of 217 kw and energy consumption of 3 MWh/d, an optimal hybrid system with 699KW solar arrays, 7 wind turbines of 100 FL, 1775 units of S6CS25P batteries and a 209 kW power inverter will be developed. The net present cost (NPC) of this system, will be 4,825,298 $ and the cost of each kilowatt-hour of energy generated by the hybrid system (COE) will be.342 dollars. Figure 18 shows the contribution of wind and solar energy in supplying the required energy of this region.

PV (kW)	FL100	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
669	7	1775	209	$ 3,761,700	83,202	$ 4,825,298	0.342	1.00
668	7	1775	212	$ 3,761,100	83,265	$ 4,825,502	0.342	1.00
669	7	1774	210	$ 3,762,000	83,207	$ 4,825,665	0.342	1.00
669	7	1777	208	$ 3,761,900	83,221	$ 4,825,746	0.342	1.00
670	7	1773	208	$ 3,762,900	83,149	$ 4,825,827	0.342	1.00
668	7	1777	211	$ 3,761,300	83,284	$ 4,825,951	0.342	1.00
669	7	1773	211	$ 3,762,300	83,212	$ 4,826,032	0.342	1.00
669	7	1776	209	$ 3,762,200	83,226	$ 4,826,113	0.342	1.00
668	7	1776	212	$ 3,761,600	83,289	$ 4,826,318	0.342	1.00
669	7	1775	210	$ 3,762,500	83,232	$ 4,826,480	0.342	1.00
670	7	1774	208	$ 3,763,400	83,174	$ 4,826,642	0.342	1.00

Figure 17. possible combinations based on increasing net present cost (NPC)

Cost Summary | Cash Flow | Electrical | PV | FL100 | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	1,544,659	67
Wind turbines	764,915	33
Total	2,309,574	100

Consumption	kWh/yr	%
AC primary load	1,103,224	100
Total	1,103,224	100

Figure 18. the contribution of wind and solar resources in supplying the required electric power

As the above figure shows, 67 percent of the region's energy is supplied by the solar array, which is due to high average amount of solar radiation in the area (6.93 Kwh/m2). In contrast, due to the relatively low average of wind speed (3.89 m / s) only 33 percent of the required energy is supplied by the turbines. Figure 28 shows the power generation rate of the hybrid system in different months of the year as well as the contribution rate of solar arrays and wind turbines in supplying the maximum power demand in this region.

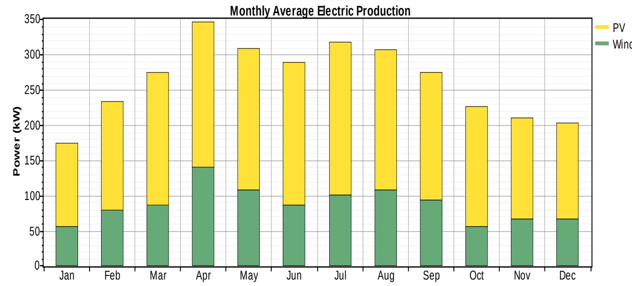


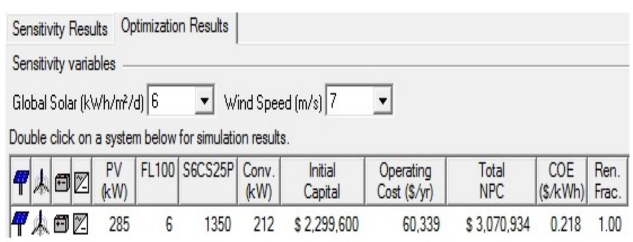
Figure 19. the rate of power generated by the hybrid system in different months of the year, based on the separated contribution of wind turbine and solar array

5-3-2 verification and generalization of results

Brest village is located in a mountainous and difficult transit zone. For this reason, construction of power distribution grids and substations, connection to the national electricity grid and maintenance of the grid will be very difficult and expensive. Thus, considering the above-mentioned conditions, the use of off-grid and distributed power generation sources seems to be a good solution. And since environmental issues and the use of clean energy is taken into considerations here, the system is merely designed based on wind and solar energy and the cost of generating a kilowatt-hour of energy (0.3420 **$**) by the hybrid system seems to be logical. The Calculated cost in similar studies carried out so far verify the calculated costs in the present study. In A study conducted in Nigeria, the cost of a kilowatt hour of energy generated by a hybrid system has been estimated at 0.824 **$** [12]. These costs were calculated as 0.575 in another study carried out in Ardebil [1]. Based on a similar study carried out in Kish Island, the cost of a 1 kWh of energy generated by a hybrid system has been estimated at **0.**337 ollars. The results obtained in this study are generalizable to other mountainous and impassable villages in the country and also to provision of a part of the energy required in the coastal towns and villages.

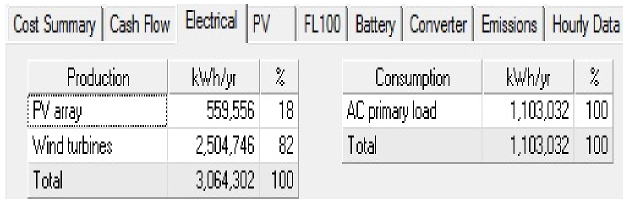
5-3-3 sensitivity analysis

Since the village of Brest is located in a mountainous area, the blow of winds with higher speed is probable, therefore the parameters of wind speed with the average values of 3.89 , 4, 5, 6 and 7 meters per second and the amount of solar radiation with average values of 5 , 5.5, 6 and 6.96 kilowatt hours per square meter were used as sensitivity variables in this case. After the simulation, HOMER, according to Figure 30, provided the most optimal composition with the average wind speed of 7 m / s and average solar radiation energy of 6 kWh / m2 / d equal to 285 kilowatt of solar array, 6 wind turbines of 100 FL, 1350 units of S6CS25P batteries and a 212 kW power inverter. As can be seen, the net present cost (NPC) of the hybrid system is 3,070,934 $ and the cost of a kilowatt-hour of useful energy generated by the hybrid system (COE) is estimated at 0.218 dollars. In this case, due to an increase in average wind speed in the region, as Figure 22 shows, 82 percent of the required energy will be supplied by wind turbines and the rest 18 percent by the solar arrays.



	PV (kW)	FL100	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
	285	6	1350	212	$ 2,299,600	60,339	$ 3,070,934	0.218	1.00

Figure 20. the optimum combination provided by the HOMER software



Cost Summary | Cash Flow | Electrical | PV | FL100 | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	559,556	18
Wind turbines	2,504,746	82
Total	3,064,302	100

Consumption	kWh/yr	%
AC primary load	1,103,032	100
Total	1,103,032	100

Figure 21. the contribution of wind and solar resources to power supply

6. Conclusion

In this paper, analysis of the wind and solar data in 4 weather stations located in Bashagard county in the East of Hormozgan province, Bandar Abbas in the center of the province and Bandar Lengeh and Khamir counties in the West, and averaging of wind speed and solar radiation during a period of 5 years from 2009 to 2013, revealed that Bashagard, Bandar Abbas, Bandar Lengeh and Khamir (at the height of 10 meters) have an average wind speed of 2.6 , 3.5 , 3.3 and 3.9 meters per second respectively and the average of solar radiation in these regions is 613.9 , 531.6 , 500.7 and 785.5 watts per square meter respectively. Then, using the AHP algorithm to determine the best location for the wind-solar plants, some criteria such as wind speed, solar radiation, the price of land, difficult transit zones and lack of tall constructions, were measured by the EC software and Bandar Lengeh with the final weight of 0.505 was chosen as the best place to construct the hybrid power plant. And Bashagard with the weight of 0.215 , Bandar Abbas with the weight of 0. 161 and Khamir with the weight of 0.119 weight were the next priorities for construction of wind solar hybrid power plant. Finally, using the HOMER software, an off-grid wind -solar power plant was designed in the village of Brest, which is located in a mountainous region at a distance of 45 km from the center of Bandar Lengeh County. The hybrid system includes 669 kilowatts of solar array, 7 wind turbines of 100 FL, 1775 units of S6CS25P batteries, and a 209 kW power inverter. The contribution of solar arrays and wind turbines to the total energy generated to supply the power of the region was 67 percent and 33 percent respectively. The net present cost of the proposed hybrid system was estimated at 4825298 and the cost of generating a kWh of useful energy by this hybrid system is 0.342 dollars**.** Since the village of Brest is located in a mountainous area enjoys a better wind condition compared to county center, the sensitivity analysis with regard to the higher wind speeds which is quite probable over the year, revealed that increase in the average wind speed in the region not only leads to an increase in the contribution of wind turbines in the supplying the needed electricity of the region, but the cost of a kilowatt-hours of electricity will be reduced to 0.218 dollars. The results of this research to other impassable mountain villages in the country and also supply part of the energy required is extended coastal towns and villages. The results obtained in this study are generalizable to other mountainous and impassable villages in the country and also to provision of a part of the energy required in the coastal towns and villages.

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