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Optimal Planning of On-Grid Hybrid Microgrid for Remote Island Using HOMER Software, Kish in Iran

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Abstract – *HOMER software functions as a tool for modeling and optimization of an energy generation micropower system based on renewable technologies. In this paper for the first time the monthly real load data have been used in HOMER to design a renewable-based microgrid in grid-connected mode for Kish Island, Iran. The calculations were performed in a way that the designed system could supply the load demand of the studied area with the lowest cost, least pollution, and highest reliability. To overcome the intermittency of renewable energy sources such as wind and solar, a combination of these sources in a hybrid system and installation of battery storage systems were considered. The solar radiation and wind speed data required by the software were obtained from the country's meteorology and NASA website and used in the software. The analysis results of four scenarios, including national grid/diesel generator, national grid/diesel generator/solar cell, national grid/diesel generator/wind turbine, and national grid/diesel generator/solar cell/wind turbine, showed the prices per kWh of $0.483, $0.505, $0.472, $0.537, respectively. In these scenarios, the share of renewable energies was 0%, 8%, 11%, and 26%, respectively. The highest amount of electricity sold to the national grid was 1597095 kWh/y for the fourth scenario which had also the lowest rate of CO_2 emissions by 4128650 kg/y.*

Keywords:*Microgrid; Hybrid system; HOMER Software, Total NPC, COE.*
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I. Introduction

Renewable energy sources are clean and unlimited, therefore they can be good substitutions for fossil fuels. The reduction in fossil fuels, higher GHGs, and higher energy consumption have led to increased use of renewable energy sources in grid-connected mode. Other factors contributing to higher application of renewable energies include the availability of various kinds of these sources, low production costs in the long run, low maintenance costs, and their safety. Integration of these sources to provide for local loads has resulted in a concept named microgrid. One of the most important issues about microgrids is their optimal operation.

According to a 2016 report, 19.2% of world energy consumption and 23.7% of power production have been supplied by renewable energies. Of these, 8.9% has been provided by traditional biomass, 4.2% from thermal energy (modern biomass, solar heating, and geothermal), 3.9% from hydroelectricity, and 2.2% electricity from wind, solar, geothermal, and biomass energies [1].

Conserving sources by developing renewable and clean energies in Iran until September 2018 was shown in Figure 1 [2].

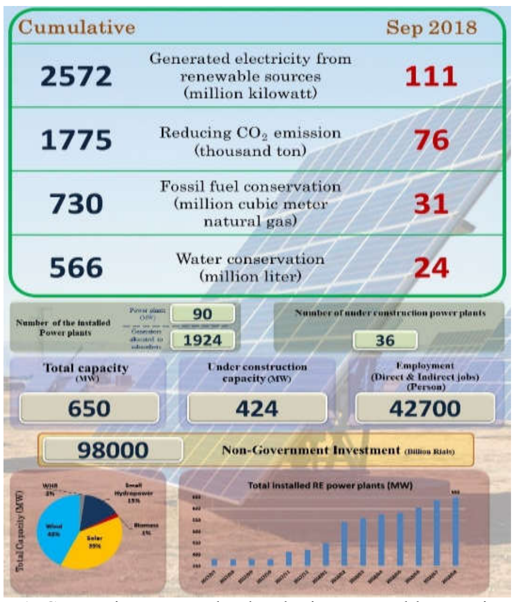


Figure 1. Conserving sources by developing renewable energies in Iran [2]

Many researchers have investigated the optimal planning and economic viability of a hybrid grid-connected microgrid from various standpoints some of which are reviewed in the following.

Lipu et al. (2017) used HOMER to conduct a design optimization and sensitivity analysis on hybrid renewable energy systems in Saint Martin village, Bangladesh [3]. Their studied system consisted of solar cells, wind turbine, diesel generator, battery, and converter. They studied 6 various scenarios for supplying 299 kWh/d. The results indicated that wind turbine/solar cell/generator scenario, which costed $359729, had the lowest price per kWh of energy equivalent to $0.27.

Peerapong et al. (2017) attempted to optimize electrification development in a diesel generator-based microgrid in an island, Thailand [4]. They used HOMER for analyses and wanted to observe how increased use of solar panels would affect the microgrid. The analyses results suggested that in case of using solar cells as well as diesel generator, the price per kWh of electricity would reduce from $0.429 to $0.374. Also, that would lead to around 797 tons of CO_2 saving annually which is due to 30251 L reduction in diesel consumption, for solar cells could provide for 41% of demand.

Soukeyna et al. (2018) used HOMER to perform a feasibility study on producing power from hybrid renewable systems for Northern coasts of Mauritania [5]. The sensitivity analysis was performed on five different prices of diesel and wind speed. Results showed that by increasing the diesel price, the price per kWh of energy would raise. Furthermore, higher wind speeds led to lower prices per kWh of energy. It is noteworthy that for wind speed more than 7 m/s, the price of energy produced would be independent of diesel price so that for 7 and 8 m/s wind speeds the price per kWh of energy generated would be $ 0.089 and $0.086, respectively.

Sadati et al. (2018) studied a hybrid wind turbine/solar cell/battery system for an island in Mediterranean area using HOMER [6]. Their aim was to calculate and optimize the net present cost, the price per kWh of energy, and total energy generated. Two various scenarios were studied with and without batteries. Results indicated that in both scenarios, the price per kWh of energy was $0.15 which was lower than that of produced by the national grid ($0.175).

Hantoro et al (2018) analyzed the energy demand and design of hybrid system in Bawean Island, Indonesia, by using HOMER [7]. The results of sensitivity analysis showed that for supplying the maximum load of 131 kW, the optimal system included solar cells (150 kW), two wind turbines (10 kW each), diesel generator (75 kW) and battery. In the optimal state, around 48% of energy was produced by solar cell, 2% by wind turbine, and the rest by diesel generator. Moreover, about 76600 kWh of surplus energy would be produced annually.

Regarding the prioritizing of different locations to harness renewable energies, Rezaei-Shouroki et al. [8] used Data Envelopment Analysis (DEA), Analytical Hierarchy Process (AHP) and Fuzzy Technique for Order of Preference by Similarity (FTOPSIS) and examined six essential criteria influencing on location optimization in order to select the most promising place in terms of providing wind energy for hydrogen production purpose. Also, Rezaei et al. [9] investigated seven different cities for establishment of a hybrid wind-solar site using five main factors including climate, geographical conditions, economy, natural disasters and social conditions. In another research, ten cities of the most suitable province of Iran, Kerman, in terms of exploiting solar energy were analyzed for the purpose of establishing a solar/hydrogen energy conversion system [10]. In another research, a hybrid model composed of DEA, Balanced Scorecard (BSC) and Game theory was proposed to rank several photovoltaic sites based on four criteria including the net cost of construction, earnings, the amount of power generated, and pollution produced per plant [11].

In terms of using solar energy for practical and applicable aims, such as water desalination and heating water, Mostafaeipour et al. [12] proposed photovoltaic systems to desalinate seawater using solar energy in coastal districts of Bushehr Province in Iran, after assessing techno-economic feasibility, the results showed that these systems are technically viable as well as economically. Several factors influencing on utilizing solar water heating systems in dry arid areas of Iran were investigated, the results indicated that environmental issues have direct effect on the use of solar water heater in the region under study [13].

One of the most important analyses before embarking on any construction is techno-economic assessment; in this regard Qolipour et al. [14] utilized HOMER and MATLAB software to propose a mathematical model for optimizing the renewable electricity price and construction of new wind power plants, simultaneously. In terms of clean hydrogen production, a wind-powered system was proposed to generate hydrogen after desalinating seawater in coastal areas of Iran [15]. Alavi et al. [16] analyzed the amount of wind energy available in five cities situated in the south eastern of Iran and examined wind turbines with different power rates to utilize them for generating hydrogen. In another research, Qolipour et al. [17] assessed constructing a hybrid solar-wind plant technically as well as analyzing economically in order to generate electricity and hydrogen using HOMER software to compare different alternatives.

In Iran, power is generally produced from fossil fuels. Given the fact that this study investigates the power supply of Kish Island, the storage limitations of fossil fuels and their resultant pollution should be taken into account. These issues as well as the fact that, in the near future, the higher fuel prices and numerous problems caused by fuel transport will hinder further development of the island, show the necessity of using alternative and renewable sources of energy. The main renewable energy sources in Kish island are wind and solar. Based on the above issues, this study is the first one to investigate the power supply of the whole island using HOMER software. The studied parameters are total NPC, COE and the amount of pollutants produced.

II. The studied area

As it is obvious in Figure 2, Kish Island is a resort island in the Persian Gulf off the southern coast of Iran. It is part of the Bandar-e Lengeh County in Hormozgan Province. It has a nearly elliptical shape and it is located 12 km off Shibkooh coast. The island has an outer boundary of 44 km, having a length of around 15.45 and a width of 7.5 km it covers an area of 90 km^2. The most elevated area is around 35 m above the sea. It lacks permanent rivers but enjoys many sources of underground fresh water. The air travel distance is 1052 km from Kish to Tehran, 250 km to Bandar Abbas, 90 km to Bandar-e Lengeh, and 28 km to Hendourabi Island. Furthermore, the nearest island to Kish is Aftab Island which is 13 km away.

Figure 2. The location of Kish on Iran's map [18]

Kish has a hot and humid climate. The median temperature is usually 27˚C and it rarely exceeds the maximum value of 32˚C. The minimum temperature never goes lower than 3˚C which occurs on a few days of winter. According to 2011 census of population and housing, Kish has a population of 24819 people which are mostly located in Kish County. The economy of Kish is under development; the main development goals include tourism and business development. According to the statistics, more than 1700000 tourists visit Kish Island every year. It has also many markets and shopping centers which constitute part the county's economy. Kish is not connected to the national grid and there is only one power-plant active in Kish. Traditionally, upon the technical problems in the power-plant or during peak hours in summers, many power blackouts occurred. Therefore, a second power-plant was planned to be constructed in the Southwest of the island which realized in 2016. In addition to gas-powered plants in Kish, there is also a diesel-powered plant with 10 MW capacity which is used for emergency [19].

III. Software presentation

HOMER functions as tool for evaluating and designing an optimal micropower in two off-grid and grid-connected modes to achieve the goals of desired applied programmers. When designing a power generation system, many decisions have to be made about its configuration: which components, such as panel, wind turbine, diesel generator, etc. will be required for building a power system? How many components are needed and what is the required size for each?

The numerous number of related technologies, their cost variability, and the availability of energy sources render decision making difficult. The optimization algorithms and sensitivity analysis of HOMER make easier the evaluation of many feasible systems [20].

HOMER shows simulation results in various tables and charts which helps in comparing different configurations based on their technical and economical rankings and enables tables and graphs to be drawn out in reports and presentations. When one intends to evaluate the effect of changes in variables such as resource availability and economic conditions on the effectiveness and economic efficiency of various system configurations, they can utilize the sensitivity analysis capability of HOMER. The results of sensitivity analysis are used for determination and identification of factors with the highest effect on the system design and operation. Also, HOMER utilizes sensitivity analysis results to answer general equations of technology options for planning and design making.

HOMER simulates the operation of a system by making energy balance equations in each of the 8760 hours of the year (time step). For each time step, HOMER compares the electric and thermal demand in that time step to the energy that the system can supply in that time step, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides in each time step when is more cost-effective to operate the generators and whether to charge or discharge the batteries. It then determines whether a configuration is feasible, i.e. whether it can meet the electric demand under the conditions that the user specifies, and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for the costs such as capital, replacement, operation and maintenance, fuel, and interest [20].

IV. The required data

IV.1. Power consumption profile

The most important data input to the HOMER is the amount of power required to be supplied by the system.

Load profile for various months of the year was shown in Figure 3.

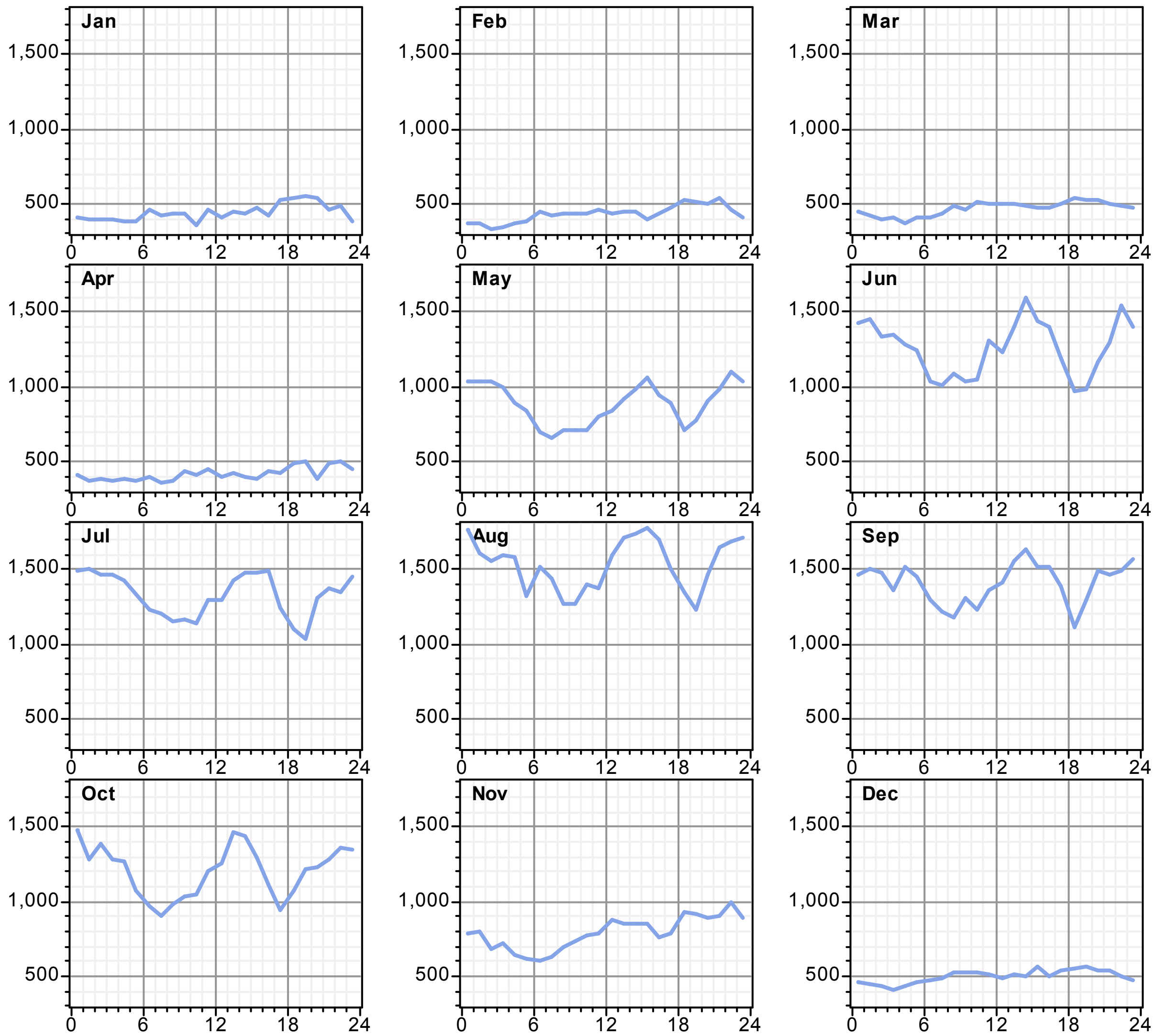


Figure 3. Load profile for various months of the year

It is clear from Figure 3 that there is a need for more electricity in the warm months of the year, from May to October, which requires cooling installations. The maximum and minimum required electric load is required in August and February respectively. Also, the minimum electricity required is happen at 6 to 12.

IV.2. Solar radiation

Monthly average solar radiation values used in HOMER are taken from NASA website [21]. To this end, the geographical latitude of 26˚32' and longitude of 53˚58' (geographical coordinate of Kish Island) were used. The monthly average solar radiation graph is shown in Figure 4.

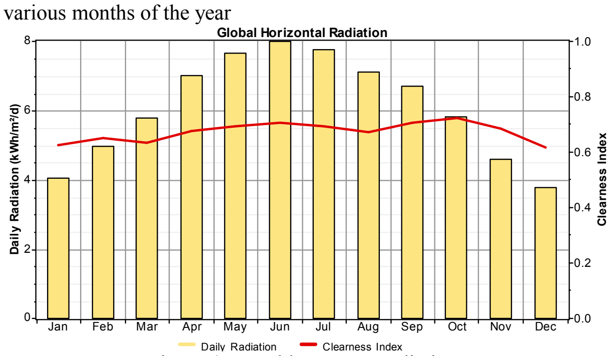


Figure 4. Monthly average radiation.

By inputting the monthly average radiation (kwh/m^2-day), the software will calculate the air clearness index by the following relation [22]:

$$K_t = \frac{H_{ave}}{H_{o.ave}} \quad (1)$$

Where H_{ave} and $H_{o,ave}$ are the solar radiation received at earth surface and top-of-atmosphere radiation, respectively. Have was taken from NANA website and according to the latitude of the studied area, the software will calculate $H_{o,ave}$ by the following relation [22]:

$$H_{o.ave} = \frac{\sum_{n=1}^{N} \frac{24}{\pi} G_{on} \left(Cos\phi \; Cos\delta \; Sinw_s + \frac{\pi w_s}{180°} Sin\phi \; Sin\delta \right)}{N} \quad (2)$$

Where ϕ is the longitude and N is the number of day in each month. Other parameters are described in the Help window of the software and will not be repeated here.

HOMER considers only the rated capacity of a PV (kW) not its area (m^2). This software does not need to know the efficiency and assumes that the PV output is directly proportional to the amount of radiation [23,24].

Defining a derating factor at the input of a PV in HOMER entails no cost. This factor is used to compensate for reduced efficiency due toenvironmental conditions which are less desirable compared to standard testing conditions. The default value for this factor is 80%. In warm weather, a slightly smaller value must be selected. The power generated by PV is calculated by the following relation [22]:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\bar{G}}{\overline{G_{C.STC}}} \right) [1 + \alpha_p (T_c - T_{c.STC})] \quad (3)$$

The parameters in the above equation are described in the Help window of the software and will not be repeated here.

IV.3. Wind speed

Kish Island is one of Iran's windy regions. Wind speed is taken from wind statistics provided by Wind Atlas Stations from Renewable Energy and Energy Efficiency Organization (SATBA) which are measured separately for each 8760 hours of the year that adds to the accuracy and precision of results [25]. Figures. 5 and 6 show the wind speed probability distribution function and average wind speed graphs for various months in Kish Island.As shown in Fig. 5, the highest percentage of wind speed distribution is belong to 4.5 to 5.5 m/s. Figure 6 also shows that the maximum monthly average wind speed is about 7 m/s and happened in March. The months of July and August with an average speed of 4 m/s are the weakest months for using wind turbines.

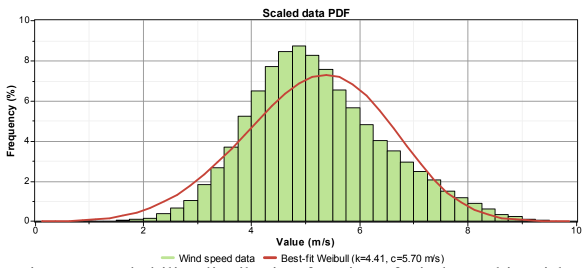


Figure 5. Probability distribution function of wind speed in Kish island.

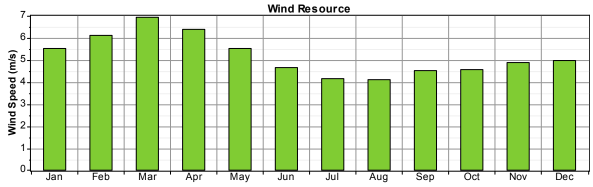


Figure 6. Average wind speed in Kish island.

HOMER uses the following relation to calculate the power output of wind turbines [22]:

$$P_{WTG} = \frac{P}{P_o} P_{WTG,STP} \quad (4)$$

In this relation for calculating wind power (P_{WTG}) in kW, $P_{WTG.STP}$ should be obtained based on the power curve of turbine for standard conditions. The power curve for the used wind turbine is shown in Fig. 7.It is clear from Figure 7 that the cut-in, rated and cut-out speed of the used wind turbine are 3, 13 and 21 m/s, respectively.

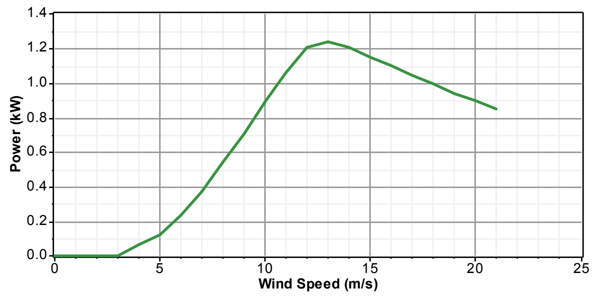


Figure 7. The power curve of the used wind turbine.

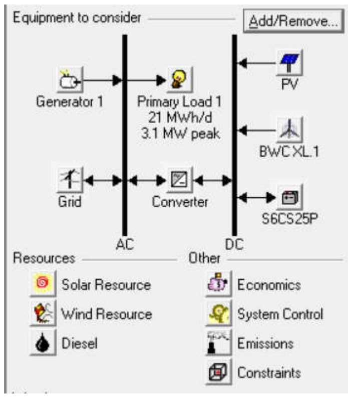
IV.4. Cost of equipment

Since diesel generator is used in the studied hybrid systems, the price input of 0.09 $/L [26] was used for diesel. Also, to take account of the annual interest rate, 18% [27] was considered as the annual real interest rate with a useful lifetime of 25 years and zero pollution penalties. Table 1 summarizes the prices, types, and sizes of equipment.

Since the studied system is connected to the national grid, the power purchasing price from the national grid was considered based on the consumption bills of 2017 in low-load, mid-load, and high-load modes to be 0.05, 0.07, and 0.12 $/kWh, respectively. According to SATBA tariffs, the power selling prices to the national grid were considered on average for low-load, mid-load, and high-load modes to be 0.318, 0.445, and 0.763 $/kWh, respectively [29]. Low-load, mid-load, and high-load hours were 23:00-8:00, 8:00-16:00, and 16:00-23:00, respectively.

Table 1. The price of equipment, the type and size of equipment [28].

Equipment	Cost ($) Capital	Cost ($) Replacement	Cost ($) O & M	Size (Kw)	Other information	Schematic
PV	6900	6900	0	1	Life time: 20 years Derating factor: 80%	
Converter	800	700	100	1	Lifetime: 15 years Efficiency: 90%	
Wind Turbine BWC XL.1	3900	3900	100	1	Lifetime: 25 years Hub height: 10 m	
Diesel Generator	900	900	0.04	1	Life time: 15000 h	
Battery Surrette 6CS25P	1200	1100	50	1	Nominal specs: 6V, 1156 Ah	



V. Results

Load supply of 21 MWh/d with a maximum value of 3.1 MW was studied in 4 scenarios. The first to fourth scenarios were to provide the power demand from the national grid, the national grid as well as solar cells, the national grid plus wind turbines, and the national grid in addition to solar cells and wind turbines. For all four scenarios, a diesel generator provided the emergency power demand.

Simulation results showed that for all four scenarios the cost per kWh of power generated is \$0.483, \$0.505, \$0.472, and \$0.537. The share of renewable energies is 0, 8, 11, and 26%, and total savings in CO_2 emitted by diesel-powered generator are 6701140, 5173898, 5395389, 4128650 kg, respectively.

As it could be seen in Fig. 8, in the first scenario 47% of electricity demand is supplied by diesel generator and 53% by the national grid. From Fig. 8 it can be observed that in January, February, March, April, and December, the national grid alone can meet the demands and the diesel generator is most needed in August. In this scenario the diesel generator runs for 2364 h/y and 2000 batteries are also used. Inverter and rectifier losses in this scenario are 185952 and 408573 kWh/y, respectively. From Table 2, which presents the data about buying/selling power from/to the national grid, it can be seen that the higher amount of power is purchased in May and the highest amount is sold in October. In this scenario, 2000 kW generator, 2000 batteries, and 1000 kW converter have been used.

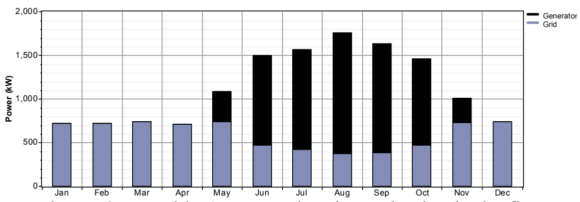


Figure. 8: Monthly Average Electric Production in the first scenario

Tab. 2: Power exchange with the grid in the first scenario

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)
Jan	535,292	103,983	431,309
Feb	482,669	91,508	391,161
Mar	550,082	93,536	456,546
Apr	510,227	101,942	408,285
May	548,196	91,127	457,069
Jun	336,016	102,206	233,810
Jul	316,947	99,213	217,733
Aug	276,072	87,291	188,782
Sep	276,698	89,096	187,602
Oct	348,102	109,409	238,693
Nov	524,033	102,880	421,153
Dec	551,092	80,085	471,007
Annual	5,255,426	1,152,276	4,103,150

In the second scenario, as it could be seen in Fig. 9, 18% of power is generated by solar cell, 29% by diesel generator, and 53% by the national grid with the total power generation of 10457491 kWh/y. From Fig. 9 it is clear that in all times of the year solar cells are used and the national grid is the least needed in April. In this scenario, solar cells produce electricity for 4381 hours of the year and generator runs for 1066 hours/y consuming 1012326 L of diesel. In the second scenario, the rectifier and inverter losses are 296062 and 306502 kWh/y, respectively. From Table 3, which summarizes the data on buying/selling power from/to the national grid, it could be seen that in all months of the year, power has been purchased purely from the national grid. In this scenario, 1000 kW solar cells, 3000 kW generator, 3000 batteries, and 1000 kW converter have been utilized.

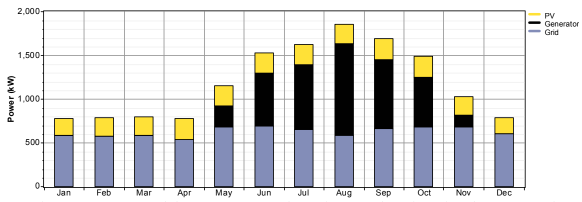


Figure. 9: Monthly Average Electric Production in the second scenario

Tab. 3: Power exchange with the grid in the second scenario

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)
Jan	438,971	136,733	302,238
Feb	386,475	120,542	265,933
Mar	433,159	126,243	306,916
Apr	389,549	137,377	252,172
May	509,452	124,033	385,419
Jun	500,749	119,942	380,807
Jul	487,897	139,101	348,796
Aug	437,220	161,787	275,433
Sep	476,916	131,249	345,667
Oct	508,068	136,304	371,764
Nov	490,398	100,003	390,395
Dec	449,965	106,977	342,987
Annual	5,508,818	1,540,290	3,968,528

In the third scenario where the price per kWh of power generated is $0.472, 1000 kW wind turbine, 1000 kW generator, 1000 kW battery, and 1000 kW converter have been used. In this scenario, of the total 9818430 kWh of electricity produced during the year, 16% is supplied by wind turbine, 47% by diesel generator, and 37% by the national grid as is shown in Fig. 10. The important point here is that wind turbines have worked for 8553 hours in the year. Consuming 1534046 L of diesel, the generator has been run for 4650 hours in the year. The rectifier and inverter losses in this scenario are 90287 and 176427 kWh/y, respectively. From Table 4, which shows the data on buying/purchasing power from/to the national grid, it can be seen that during a year, 3642711 kWh of electricity is bought from the national grid and 1497550 kWh of electricity is sold to the national grid. As in the second scenario, the electricity bought is higher than that sold during one year. In this scenario, in 5 months of the year (January, February, March, April, and December), the electricity sold to the national grid is higher than that bought with its peak in March.

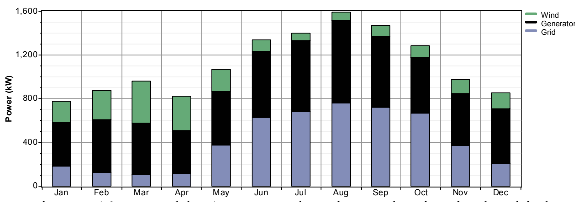


Figure. 10: Monthly Average Electric Production in the third scenario

Tab. 4: Power exchange with the grid in the third scenario

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)
Jan	140,128	206,947	-66,819
Feb	84,725	255,376	-170,651
Mar	78,688	310,927	-232,239
Apr	85,382	245,100	-159,718
May	282,354	95,971	186,383
Jun	452,516	22,674	429,842
Jul	511,307	14,790	496,517
Aug	569,019	6,578	562,442
Sep	519,630	8,291	511,339
Oct	495,745	20,833	474,912
Nov	267,048	98,327	168,722
Dec	156,168	211,737	-55,569
Annual	3,642,711	1,497,550	2,145,162

In the fourth scenario which is associated with the lowest amount of pollution and the higher use of renewable energies, wind and solar combination has been used for supplying the electricity demand through a hybrid system connected to the national grid and diesel generator. In this scenario, 1000 kW solar cell, 1000 kW wind turbine, 2000 kW diesel generator, 2000 kW battery, and 1000 kW converter have been used for power generation. 19% of the electricity is generated by solar cells, 15% by wind turbines, 31% by diesel generator, and the rest by the national grid as is shown in Fig. 11. From this figure it can also be seen that in all times of the year solar cells and wind turbines have been used and the highest use of diesel generator occurs in August. The running hours of solar cell, wind turbine, and diesel generator for the whole year are 4381, 8553, and 1609 hours, respectively. In this scenario, as in the second and third ones, batteries are used and therefore the rectifier losses are equal to 132046 kWh. Also, annual inverter losses in this scenario are 370194 kWh/y which is the highest among four scenarios. Due to more power generation from renewable energies in this scenario, it has the highest annual rate of selling electricity to the national grid by 1597095 kWh (Table 5).

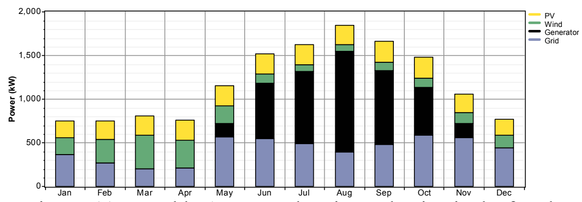


Figure. 11: Monthly Average Electric Production in the fourth scenario

Tab. 5: Power exchange with the grid in the fourth scenario

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)
Jan	271,284	138,233	133,052
Feb	180,622	124,174	56,447
Mar	149,039	144,696	4,343
Apr	155,062	148,227	6,836
May	421,780	113,852	307,928
Jun	396,863	125,524	271,338
Jul	366,348	151,579	214,769
Aug	294,294	164,486	129,808
Sep	343,348	120,883	222,464
Oct	436,998	134,254	302,744
Nov	404,091	120,162	283,928
Dec	331,319	111,022	220,297
Annual	3,751,048	1,597,095	2,153,953

VI. Conclusion

In order to reduce greenhouse gas emissions and encouraging higher use of renewable energies in Iran and consistent with the previous research by the authors [30-46], this paper is the first one to investigate the real data of electricity consumption in an island for 12 months of the year using HOMER in four various scenarios to analyze hybrid wind-solar systems in grid-connected mode. Results indicated that:

- Economically, the national grid/diesel generator is the most cost-effective system having price per kWh of electricity of $0.483.

- The highest use of renewable energies by 26% is related to the national grid/diesel generator/solar cell/wind turbine scenario which also produces the least CO_2 emissions by 4128650 kg/y.

- In none of the scenarios the annual net electricity sold to the national grid is higher than that bought from the national grid.

- The most amount of electricity sold to the national grid occurs in the national grid/diesel generator/solar cell/wind turbine system by selling 1597095 kWh of electricity annually.

- The solar cell-based scenario is more costly than wind turbine-based but it produces less pollution.

- Due to low price of diesel in Iran compared with national grid and renewable-based electricity, diesel generator is used in all scenarios necessarily.

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