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Finding the Minimum Distance from the National Electricity Grid for the Cost-Effective Use of Diesel Generator-Based Hybrid Renewable Systems in Iran

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ABSTRACT

The electricity economy and its excessive consumption have become one of the main concerns of the Iranian government for many years. This issue, along with recent droughts, shows the need to use renewable energy that is free and clean and does not require water. In addition, due to the high cost of cable-laying and maintenance of power lines, it is not at all an option at all distances over the development of the national electricity grid. Therefore, it is important to find a distance for farther distances so that the use of renewable energy systems can be superior to the national electricity grid. According to related studies conducted so far, nothing has been done in this regard in Iran untill private-sector investors realize that, for what distances from the national grid, the network development is not cost-effective compared to using renewables. Therefore, in the present work, by using NASA's wind and solar data, 102 stations in Iran were investigated using the HOMER software. The studied system is a solar-wind one backed up by batteries and diesel generator for emergency conditions. The results showed that the average total net present cost of the solar-wind hybrid system in Iran was to provide a daily average electricity load of 5.9 kWh of a residential building with a peak load of 806 W equal to $ 12415, which could on average provide 95.3 % of the building's needs by renewable energy. The average minimum distance from the national grid is 593 m for the cost-effective use of renewable energy.

1. INTRODUCTION

Given the decline in hydrocarbon energy in the future, the use of renewable energy all around the world has received attention more than ever. In countries that enjoy oil and gas resources such as Iran, the actions taken in this area are still not noticeable. One of the reasons is the high cost of generating electricity from renewable energies such as solar and wind in Iran despite the potential of using such energy in comparison with other countries. Certainly, by eliminating subsidies and comparable energy production from oil and gas with renewable energies, the current trend will surely change, and it is expected that the use of renewable energy be more appropriate in the future in Iran [1]. Decreasing the severity of climate change has been the main reason for a 100 % renewable energy future. However, benefits of renewable energies, such as reducing CO_2, are not the only motivations for their expansion. Another important motive is energy security [2].

Transmission of electrical energy allows for easy utilization of electricity without paying the regular costs involved in fuel transportation and related pollutions. Though in some cases, like hydropowers in dams, the only possible way is the transmission of electrical energy. For farther distances, electrical energy is usually transported by overhead lines. In their calculations, engineers involved in designing transmission lines do their best to increase the transmitted power as much as possible. However, they are also required to take into account such considerations and limitations as network safety, network development, route limitations, etc. in their designs to ensure continuous electrification. Other limitations include fusion (melting) of lines due to excessive electrical current, bowing of transmission lines due to overheat and approaching the ground, high voltage, costs of pylons, etc.

Generally, five main challenges in Iran’s electric industry, announced by the World Bank, include supply of natural gas to power plants, high debts of electricity utilities and their unprofitability, power losses along transmission lines, low price of electricity, and improper consumption of electricity. Therefore, to solve electric industry problems, the government has adopted such policies as participation of private sector in electricity generation and creating more competitive markets. Another solution with a very desirable influence on the environment is the use of renewable energies that are particularly efficient for impassable regions remote from the main power grid, and it has such benefits as decentralization of power generation and distribution sectors and elimination of losses in the transmission phase.

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Given the aforementioned issues, for encouraging private sector participation in this industry, a comparison has to be performed between the renewable energies and the main power grid to determine the fixed costs (initial investment) and present costs (repair and maintenance) in both scenarios of using the main grid and renewable energies by considering the losses due to power outages. To this end, an optimal distance has to be specified beyond which the use of renewable energies outweighs the costs of cabling and maintenance of main grid lines. Before deciding about the construction of power transmission lines, some technical, economic, and environmental studies must be performed to determine whether construction of transmission lines as the only way of supplying electricity or renewable energies can be an alternative or not.

In 2016, new records on the installed capacity of renewable electricity were received. This year, with the addition of 161 GW, the total renewable energy in the world increased by 9 % compared to 2015. Photovoltaics accounted for about 47 % of the total increase, followed by wind power of 34 % and hydroelectric power by 15.5 % in 2016. Meanwhile, for the fifth consecutive year, investment in renewable electricity has almost doubled its investment in new fossil fuels and reached $ 249.8 billion [3].

In 2016, for the third consecutive year, despite a 3 % growth of the global economy and the increasing demand for energy, the amount of CO_2 produced by fossil fuels and the industry remained constant. This could be mainly due to the reduction of coal consumption and the growth of renewable energy capacity and the improvement of energy efficiency. The Sustainable Energy Movement for All initiative aims to provide sustainable energy access for all people, double the share of renewable energy from 18 % in 2010 to 36 % in 2030, and double the global rate of energy efficiency by 2030 [3].

In the following, some recent studies have been carried out that examine the minimum distance to the national grid for cost-effective use of the renewable energy system.

The availability of electricity is a crucial component of health facilities in developing countries. Munuswamy et al., in a 2011 study, analyzed and estimated the cost of electricity to a rural health center in India with a decentralized renewable energy system (fuel cell-based system) using HOMER software [4]. The results indicated that if the distance from the national grid was less than 24 km, the electricity supply from the national grid was cheaper than an off-grid renewable system.

Sanchez et al. (2015) investigated the production of renewable energy for electricity to remote communities in the Amazon region [5]. Generating electricity through diesel fuel is traditionally the only option for this region. According to the results, when the cost of power transmission lines due to issues of distances, dispersal, and maintenance is excessive, the use of distributed generation is the only solution, and it is expected that biomass-based electrical systems have an important role in providing electricity to these remote rural communities where there is abundant agricultural waste.

Kim et al. (2017) carried out a study using the HOMER software aimed at finding a hybrid energy system with appropriate technology and economic conditions for KEPCO Company, South Korea's Gasado Island and introduced the best combination system [6]. The proposed system is a combination of PV cells, wind turbines, fuel cells, batteries, hydrogen storage systems, electrolyzers, and diesel generators. The results revealed that an off-grid system was superior to grid-connected system, when the distance was more than 149 km away from the national electricity grid.

Considering the electrical demand data and weather data for wind speed and solar radiation at the University of Obafemi, Awolowo, Adewuyi, and Komolafe in 2016, the optimal design of an off-grid renewable energy system, including wind and solar power sources, hydropump, battery, and diesel generator as support for this university was explored [7]. The results illustrated that the total cost of installing and setting up a hybrid renewable energy system was estimated to be $ 3692152.5, while the installation and setting up of the power grid with a cabling cost of 20000 $/km was a cheaper option for a distance of up to 180 km.

In 2018, Jahangiri et al. studied the use of wind energy, solar energy, and biomass to generate electricity and heat simultaneously in Zarrin Shahr, Isfahan province, Iran [8]. The results showed that if the distance to the access point to the national grid in the study site is less than 2.58 km, then grid electricity is better than using biomass. In addition, considering the assumption of the increase of 15 % in electricity and gas prices, if 100 % of the energy needed by renewable energy sources in the next 25 years is provided, it will gain a profit of $ 20,310.

In recent years, the electricity industry has seen good days; however, there have been some challenges that make the situation hard at times. Construction of new power lines, besides imposing high costs of equipment and construction over impassable places or valuable and restricted lands and invading their territory, is a costly, time-consuming and, at times, impractical solution. This has encouraged the government to appeal to a more reasonable and cheaper alternative, that is, using renewable energies which are also more environment-friendly. The people of Iran do not use electricity efficiently and the losses of electricity in buildings and factories are quite high. Therefore, much energy is consumed in Iran is compared to gross domestic product [9].

According to the studies, no study has been conducted so far in Iran to find the minimum distance from the national grid for cost-effective installation of hybrid renewable systems. This will help private-sector investors or owners of buildings far away from the national power grid to make better decisions. Given the climate diversity in Iran, data obtained in the present work for a particular station are applicable and comparable for other points around the world with the same climate conditions. Therefore, in the present work, by using the HOMER software and considering wind and solar data of 102 stations extracted from the NASA site, the parameters such as cost (per kWh) of produced electricity, the total net present cost, and the minimum distance to the national electricity grid have been examined.

2. LOCATION AND STATIONS

Iran is located in the Southwest of Asia and in the Middle East with 1648195 km^2 (the eighteenth country in the world) and based on the 2016 census; it is home to 79926270 people (ranked eighteenth). Iran is neighboring from the north with Azerbaijan, Armenia and Turkmenistan, from the east with Afghanistan and Pakistan, and from the west with Turkey and Iraq, and also from the north to the Caspian Sea and from the south to the Persian Gulf and the Oman Sea; important areas include oil and gas extraction sites in the world.

To investigate the minimum distance in order to optimize the use of the renewable energy hybrid system in Iran, solar radiation and wind speed of 102 stations were extracted from NASA website; then, by means of GIS software, wind speed and solar radiation maps are plotted (Figures 1 & 2). The locations of the stations examined are visible on the maps. Data from wind speed and solar radiation have been used as inputs to the HOMER software for carrying out technical, economic, and environmental calculations.

3. SIMULATION SOFTWARE

HOMER software has the task of evaluating and designing optimal micropower in two off-grid and on-grid to have access to the intended applications. When a power system is designed, many decisions should be made about the system configurations: what components such as panels, wind turbines, diesel generators, etc. are required to build a power system? What number and size should be used for each component? Many technologies are used, and the cost changes of these technologies and the availability of energy resources make it difficult to make these decisions. HOMER software optimization and sensitivity analysis algorithms make the evaluation of many possible systems easier [10].

After simulating the possible configurations of the system, Homer presents a list of configurations according to the total net present cost that can be compared to various system design options. When sensitivity variables are defined as inputs, Homer repeats the optimization process for each sensitivity variable that is specified. For example, if wind speed is defined as a sensitivity variable, Homer simulates system configurations for a range of speeds that are specified [11].

In the following, the relations used in the software to estimate the size and quantity of components in the hybrid systems and also the calculation of costs are presented [12].

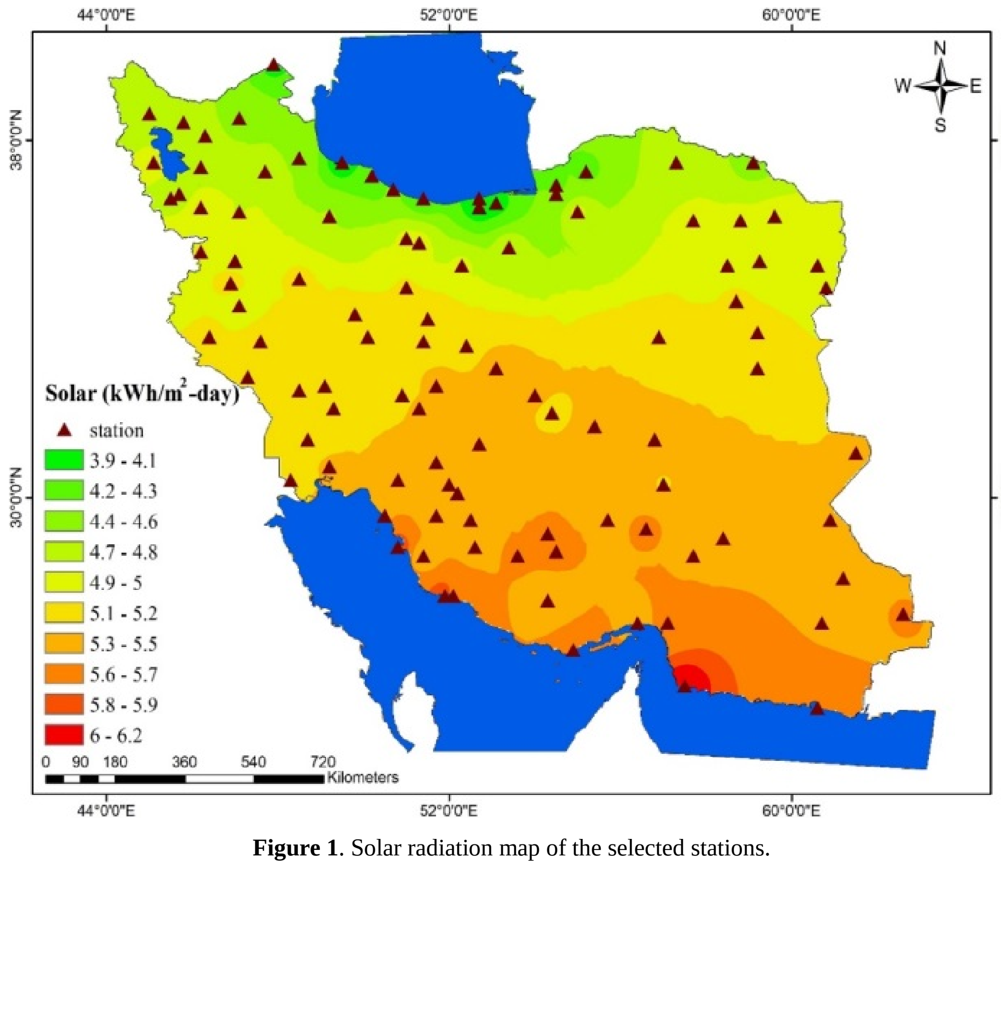


Figure 1. Solar radiation map of the selected stations.

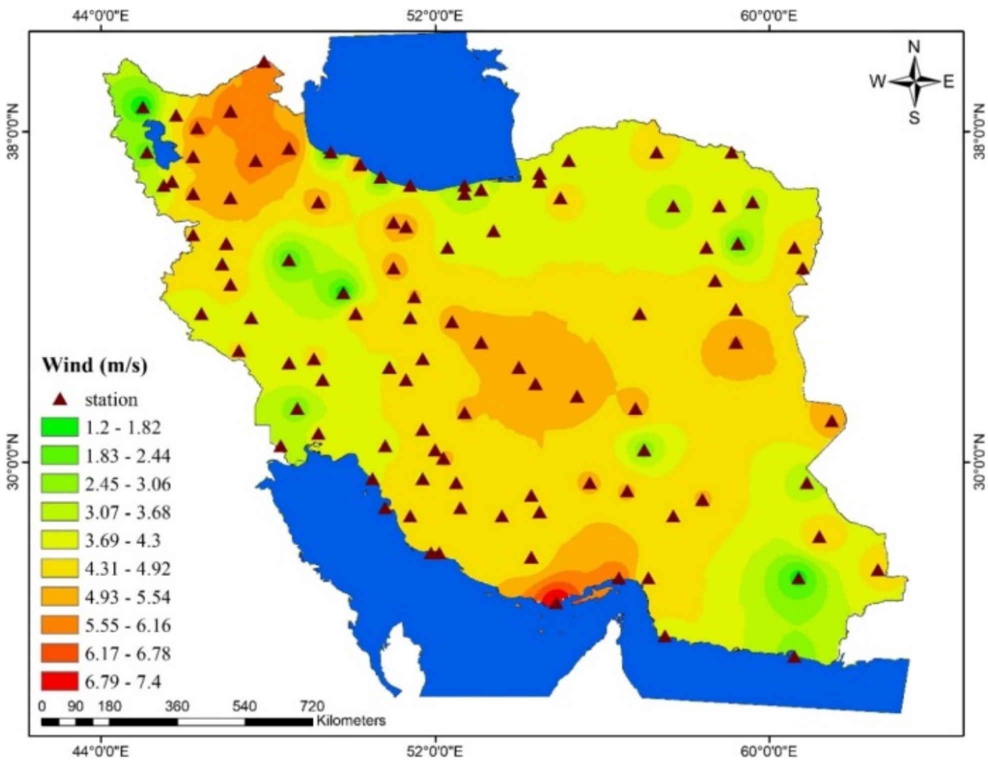


Figure 2. Wind speed map of the selected stations.

3.1. Solar cells

To calculate the output power of PV cells, Homer uses the following relation:

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

where Y_{pv} is the output power (kW) of solar cell under standard conditions, f_{pv} is the derating factor, ($\overline{G_T}$) is the incident radiation on the cell's surface on a monthly basis (Kw/m²), ($\overline{G_{T.STC}}$) is the incident radiation on the cell's surface (1 Kw/m²) under standard conditions, α_p is the temperature coefficient of power (%/°C), T_c is the cell's surface temperature (°C) at each time interval, and $T_{c,STC}$ is the cell's surface temperature under standard conditions (i.e., 25 °C). Due to the fact that the selected cell does not include the temperature effect in the simulations, αp has a value of zero in the current study.

3.2. Wind turbine

Using the power and wind speed curve at hub height, HOMER calculates the output power of wind turbines. Note that power curve generally captures the wind turbine performance under standard temperature and pressure conditions. To calculate it under real-world conditions, as it is shown in the following relation, the software multiplies the power curve output by the air density ratio.

$$P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG.STP} \quad (2)$$

where ρ is the real air density (kg/m³), ρ_0 is the air density under standard temperature and pressure conditions equal to 1.225, and $P_{WTG,STP}$ is the wind turbine output power under standard conditions.

Statistical methods were used to determine the wind energy potential in one of the areas of interest and to estimate the energy output of this site. A function that has proved accurate based on the measurements in various parts of the world is Weibull probability density distribution that requires k (shape factor) and c (scale factor) parameters as in the following form [13]:

$$p(U) = \left(\frac{k}{c} \right) \left(\frac{U}{c} \right)^{k-1} \exp\left[-\left(\frac{U}{c} \right)^{k} \right] \quad (3)$$

where the scale parameter, c, indicates how strong the wind in a location is, while the shape parameter, k, means how peaked the wind distribution is, i.e., if the wind speeds tend to be very close to an absolute value, the distribution will have a high k-value and be very peaked. The empirical relations are used to determine k and c.

Wind turbines can convert 50 % of the available wind energy into electricity. The turbine's power output (P) is given by the following relation [14]:

$$P = \frac{1}{2} \rho A V^3 C_p \quad (4)$$

where ρ is the air density [kg/m^3], A is the swept area [m^2], V is the wind speed [m/s], and C_p is the turbine's power factor for the corresponding wind speed.

The wind energy potential for installing wind turbines is regarded as poor (<4 m/s), marginal (< 4-4.5 m/s), good to very good (5.5-6.7), and excellent (> 6.7 m/s) [15].

Since Iran is both a land- and sea-locked country, wind turbulence analysis of its stations is of high importance since the wind turbines are designed based on the wind speed and wind turbulence specifications [14]. In addition, turbulence significantly affects the applied fatigue loads on wind turbines, and a high level of turbulence reduces power generation and accelerates the fatigue of mechanical components [16, 17]. The following relation gives turbulence intensity:

$$TI = \frac{\sigma}{V_{ave}} \quad (5)$$

where σ is the standard deviation, and V_{ave} is the average wind speed. The intensity of turbulence is ranked as low, mid, and high if it is ≤ 0.1, 0.1-0.25, and ≥ 0.25 [16], respectively.

3.3. Batteries

In each time step, HOMER calculates the maximum amount of power that the storage bank can absorb. The maximum charge power varies from one time step to the next according to its state of charge and its recent charge and discharge history. HOMER imposes three separate limitations on the battery's maximum charge power. The first limitation comes from the kinetic battery model which is calculated by the following relation:

$$P_{batt.cmax.kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc(1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \quad (6)$$

where Q_1 is the available energy (kWh) in the battery at the beginning of the time step, Q is the total amount of energy (kWh) in the battery at the beginning of the time step, c is the battery capacity ratio, k is the battery rate constant (1/h), and Δt is the length of the time step (h).

The second limitation relates to the maximum charge rate of battery which is given by:

$$P_{batt.cmax.mcr} = \frac{(1-e^{-\alpha_c \Delta t})(Q_{max}-Q)}{\Delta t} \quad (7)$$

where α_c is the battery's maximum charge rate (A/Ah), and Q_{max} is the total capacity of the battery (kWh). The third limitation relates to the battery's maximum charge current, which is given by the following equation:

$$P_{batt.cmax.mcc} = \frac{N_{batt} I_{max} V_{nom}}{1000} \quad (8)$$

where N_{batt} is the number of batteries, I_{max} is the battery's maximum charge current (A), and V_{nom} is the battery's nominal voltage (V). According to the following relation, HOMER sets the maximum battery charge power equal to the least these three values.

$$P_{batt.cmax} = \frac{\mathrm{Min}\,(P_{batt.cmax.kbm}\cdot\ P_{batt.cmax.mcr}\cdot\ P_{batt.cmax.mcc})}{\eta_{batt.c}} \quad (9)$$

where $\eta_{batt,c}$ is the charge efficiency of the batteries.

3.4. Diesel generator

By introducing the fuel curve inputs, HOMER draws the corresponding efficiency curve. The fuel curve describes the amount of fuel the generator consumes to produce electricity. HOMER assumes that the fuel curve is a straight line. The following relation gives the generator's fuel consumption in units/hr as a function of its electrical output:

$$\dot{m}_{fuell} = F_0 Y_{gen} + F_1 P_{gen} \quad (10)$$

where F_0 is the fuel curve intercept coefficient (units/hr.kW), F_1 is the fuel curve slope (units/hr.kW), Y_{gen} is the rated capacity of the generator (kW), and P_{gen} is the electrical output of the generator (kW). The generator's electrical efficiency, which is defined as the electrical energy coming out divided by the chemical energy of the fuel going in, is calculated by the following relation in HOMER:

$$\eta_{gen} = \frac{3.6\ P_{gen}}{\dot{m}_{fuel} LHV_{fuel}} \quad (11)$$

where LHV_{fuel} is the lower heating value of the fuel (MJ/kg).

3.5. Converter

The inverter efficiency determines how much of the DC power is converted to AC power. Converter may be a synchronous inverter (with AC generator) or a switched inverter. Rectifier efficiency is defined as the ratio of DC power to the applied AC power. It should be noted that HOMER assumes constant values for inverter and rectifier efficiencies. While most solid-state converters are less efficient at lower loads due to standing losses.

3.6. Cost computations

Discount rate is used to convert one-time costs into equivalent annual costs. HOMER uses interest rates to give discount factor and calculate the annual costs from NPCs. To calculate annual real interest rate (i) from nominal interest rate (i'), HOMER uses the following equation:

$$i = \frac{i' - f}{1 + f} \quad (12)$$

where f is the annual inflation rate. HOMER assumes a constant inflation rate for all costs. The total NPC is captured by dividing total annual cost by capital recovery factor. HOMER calculates the capital recovery factor (CRF) by:

$$CRF = \frac{i\,(1+i)^N}{(1+i)^N - 1} \quad (13)$$

In addition, the price per kWh of electricity produced is obtained by total annual costs divided by the real cost of electrical load.

4. REQUIRED DATA

The schematic of the hybrid studied system is shown in Figure 3. Figure 3 shows that the annual average of requirement consumption load is 5.9 kWh/day with a peak of 806 W. The consumption load daily profiles over a period of 12 months are shown in Figure 4. Figure 4 shows the daily average load profile for various months of the year which is read from the electricity meter and is eventually expressed as an averaged value for each month.

Monthly average of solar radiation and wind speed data are shown in Figures 1 and 2. The data extracted from the NASA site are average for 20 years [18]. By introducing the average monthly data in the software, the software defines the coefficient of air clearness index due to the latitude of the site, indicating the deficit of radiation outside the atmosphere that has reached the surface of the earth [19]. This coefficient is about 0.25 for a very cloudy sky and 0.75 for a perfectly clear sky. The air clearness index for the 102 stations under study is shown in Figure 5.

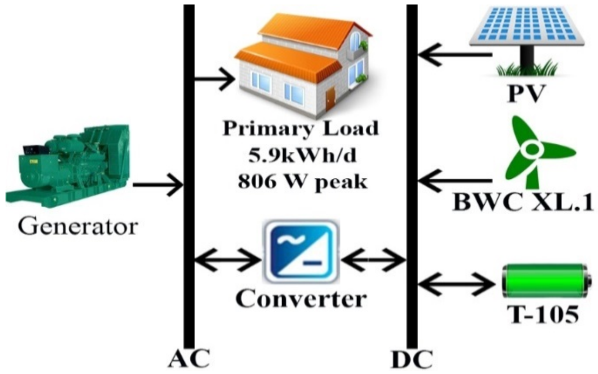


Figure 3. Schematic of hybrid system under study.

Accordingly, when calculating the wind turbine power output by HOMER software, it is necessary to know the air density at the height of the turbine installation; therefore, the height of each station from the sea level is a determinant [20]. The turbine power curve, which is the wind turbine output power in terms of wind speed in standard conditions, is shown for the used BWC XL 1.25kW turbine in Figure 6. It is assumed that the height of the turbine hub to the ground level is 25 m. Table 1 shows other information about the price of equipment used, lifetime, size, and type.

According to Figure 3, because of the diesel generator used in the hybrid system, the price of diesel consumed was 0.19214$ in the software [21]. In addition, the lifetime of the project was 25 years and the real annual interest rate was 19 % [22]. It is noteworthy that the stated price for diesel is taken from [21] without considering subsidies, and annual interest rates are also based on the figures published in the reputable Trading Economic website [10, 11]. Since this study aims to compare the cost of electricity produced from the renewable energy hybrid system with that of the national grid; by collecting data from the maintenance and repair experts of the electricity distribution company, the price of cable-laying, annual operating & maintenance, and average price of national electricity grid were considered as 14038.8 $/km, 510.5 $/km, and 0.07 $/kWh, respectively [8]. The cable used for transmitting the single-phase electric power was made of copper with two strands of wire round in cross-section, each with an area of 35 mm^2. The price per kWh of grid electricity is the average of three states of high load, mid load, and low load.

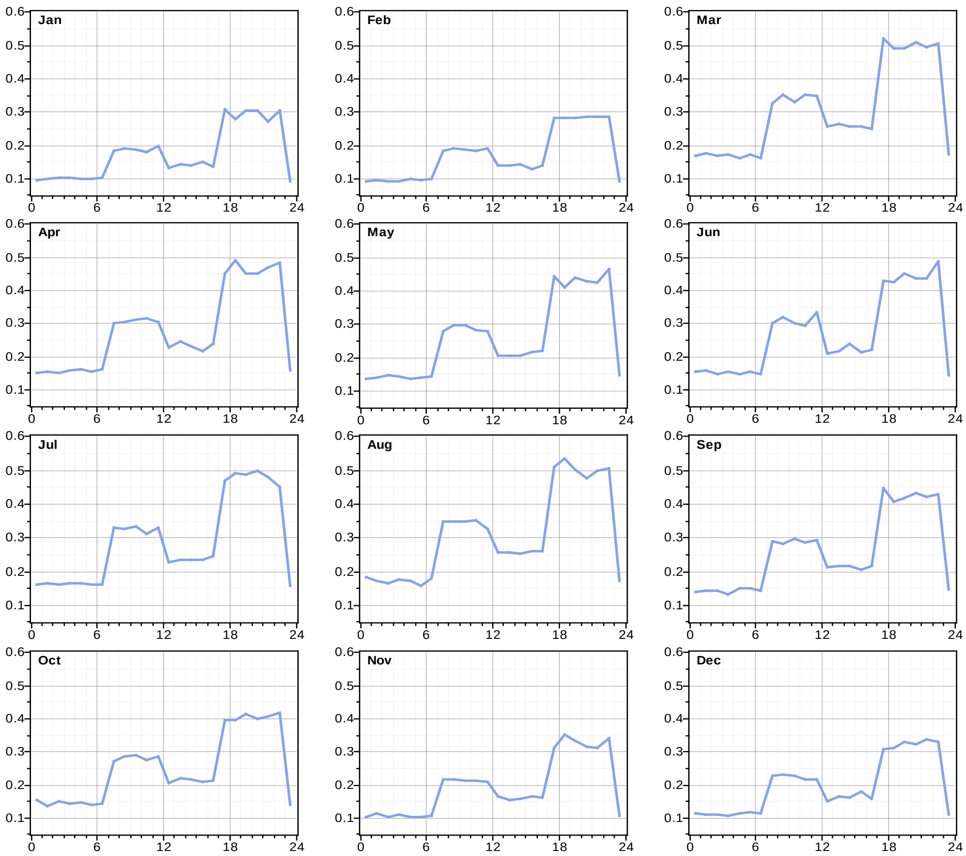


Figure 4. Daily profiles of consumption load over a year.

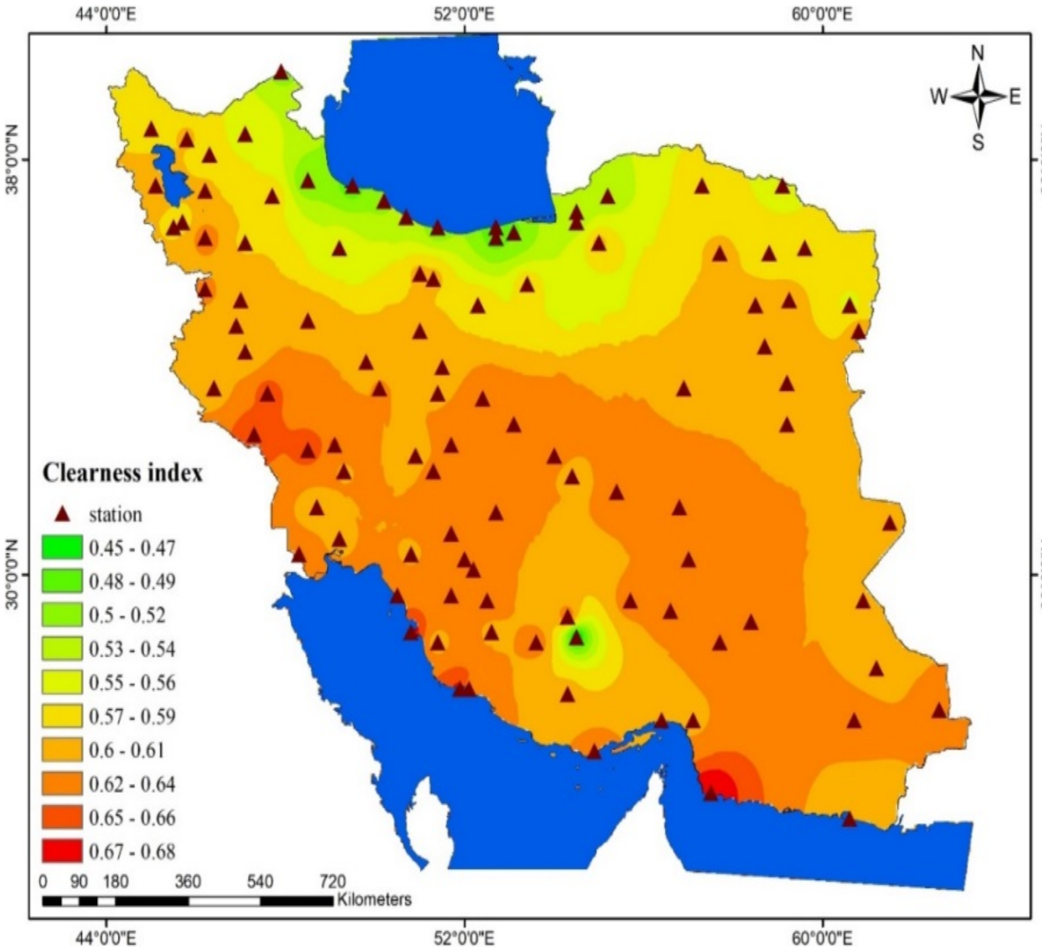


Figure 5. Clearness index for 102 stations under study.

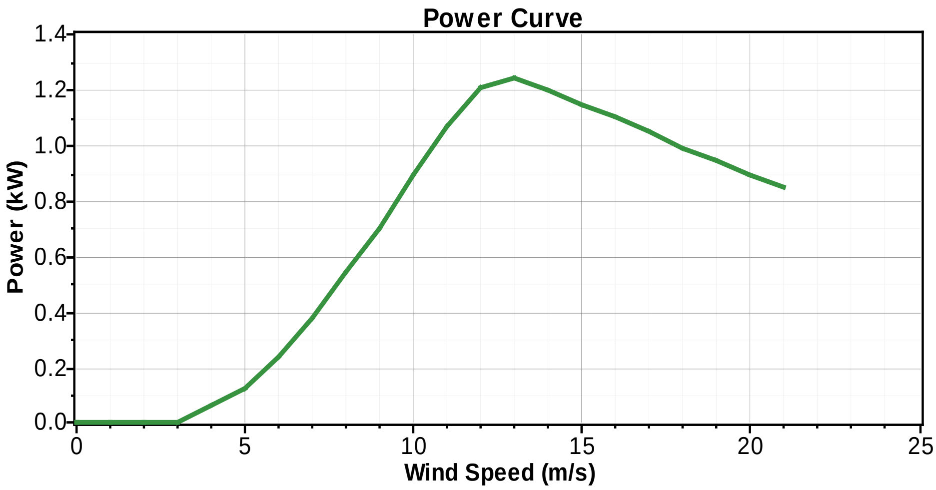


Figure 6. Power curve of under study wind turbine.

Based on the statistics published on SATBA website [22], the cost of selling electricity to the national grid is as presented in Table 2 [23]. In addition, the foreign exchange rate is 1 IRR = 0.00002 USD in Iran [24].

In addition, since there are no penalties and taxes for fossil fuel pollution in Iran [25], the penalty for pollutants in this paper is zero.

5. RESULTS AND DISCUSSION

The investigation results of 102 stations under study are given in Table 3. The parameters studied for each station include the type of equipment used to supply electricity, the total net present cost, the cost per kWh of energy, and the minimum distance to the national grid in order to optimize the use of the renewable energy hybrid system.

Table 1. Simulated hybrid plant information [12].

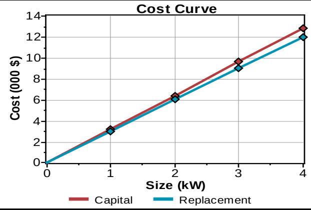
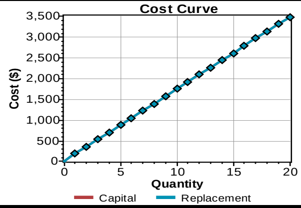
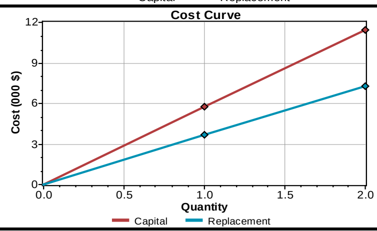
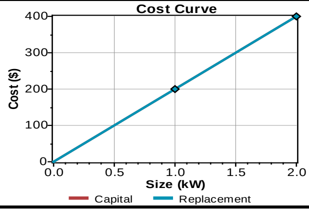
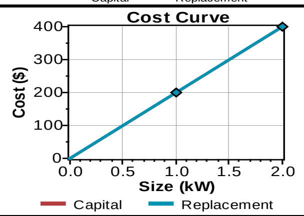
Component	Purchase ($)	Replacement ($)	Operating & Maintenance ($)	Lifetime	Size of equipment
PV	3200	3000	0	20 year	
Battery Trojan T-105	174	174	5	845 kWh	
Wind turbine BWC XL.1	5725	3650	100	20 year	
Converter	200	200	10	10 year	
Generator	200	200	0.5	15000 hour	

Table 2. The basic tariff for the purchase of electricity from renewable energy plants [23].

Row		Technology type	Guaranteed electricity purchase tariff (IRRs per kWh)
1	Biomass	Landfill	2700
		The aerobic digestion of manure, sewage, and agricultures	3500
		Incineration and waste gas storage	3700
2	Wind farm	above 50 MW capacity	3400
		With a capacity of 50 MW and less	4200
		With a capacity of 1 MW and less	5700
3	Solar farm	above 30 MW capacity	3200
		With a capacity of 30 MW and less	4000
		With a capacity of 10 MW and less	4900
		With a capacity of 100 kW and less	7000
		With a capacity of 20 kW and less	8000
4	Geothermal (including excavation and equipment)		4900
5	Waste recycling in industrial processes		2900
6	Small hydropower	Installation on the rivers and side facility of dams	2100
	With a capacity of 10 MW and less	Installation on the pipelines	1500
7	Fuel cell systems		4948
8	Turbo expanders		1600

The results of Table 3 reveal that the most suitable and unsuitable stations in Iran to use the renewable energy hybrid system are Bandarabbas and Darab, respectively. In Bandarabbas, the minimum distance from the national electricity grid for the cost-effective use of renewable energy is 536 m, which is the lowest value among 102 stations. The lowest electricity price among all the stations under study is 0.58 $/kWh for Bandarabbas, which is achieved for the total net present cost of $ 11378. In Darab, the minimum distance from the national grid for the cost-effective use of renewable energy is 712 m, which is the highest value among 102 stations.

Table 3. Results of simulations.

Station	Equipment (Except Conv. & Gen.)	Total NPC ($)	COE ($/kWh)	Ren. Frac. (%)	Distance to grid (km)
Ahwaz	PV (2), Batt (13)	12414	0.633	98	0.591
Abadan	PV (2), Batt (10)	11965	0.610	97	0.567
Abadeh	PV (1), Batt (10)	11944	0.609	98	0.566
Ahar	WT (1), Batt (10)	12782	0.652	82	0.611
Arak	PV (2), Batt (11)	12332	0.629	96	0.587
Alvand	PV (2), Batt (13)	12933	0.659	93	0.619
Anzali	PV (2), Batt (15)	14143	0.721	85	0.684
Aq Qaleh	PV (2), Batt (16)	13450	0.686	93	0.647
Ardakan	PV (2), Batt (11)	12031	0.613	99	0.571
Ardestan	PV (2), Batt (10)	11930	0.608	98	0.565
Babol	PV (2), Batt (15)	14151	0.721	86	0.684
Bafq	PV (2), Batt (10)	12019	0.613	98	0.649
Baft	PV (2), Batt (10)	12014	0.613	98	0.570
Bam	PV (2), Batt (11)	12122	0.618	98	0.576
Babolsar	PV (2), Batt (15)	14105	0.719	86	0.682
Bandar-e Genaveh	PV (2), Batt (10)	11984	0.611	97	0.568
Bandar-e Lengeh	PV (2), Batt (10)	12001	0.612	98	0.569
Bandar-e Mahshahr	PV (2), Batt (11)	12371	0.631	95	0.589
Borujen	PV (2), Batt (11)	12192	0.622	97	0.579
Bukan	PV (2), Batt (11)	12502	0.637	95	0.680
Bandarabbas	WT (1), Batt (10)	11378	0.580	94	0.536
Birjand	PV (2), Batt (11)	12386	0.632	96	0.590
Bojnord	PV (2), Batt (13)	12769	0.651	95	0.610
Bushehr	PV (1), Batt (10)	11789	0.601	99	0.558
Chabahar	PV (2), Batt (12)	12303	0.627	98	0.585
Chalus	PV (2), Batt (15)	14053	0.716	86	0.679
Darab	PV (2), Batt (14)	14669	0.784	80	0.712
Dargaz	PV (2), Batt (15)	13266	0.676	94	0.637
Dehloran	PV (2), Batt (10)	11956	0.610	98	0.567
Dezful	PV (2), Batt (11)	12005	0.612	98	0.569
Dir	PV (2), Batt (10)	11800	0.602	99	0.558
Do Gonbadan	PV (2), Batt (12)	12303	0.627	98	0.585
Do Rud	PV (2), Batt (10)	11909	0.607	98	0.564
Firuzabad	PV (2), Batt (11)	12205	0.622	97	0.580
Garmsar	PV (2), Batt (12)	12597	0.642	95	0.601
Gonabad	PV (2), Batt (11)	12319	0.628	96	0.586
Gonbad-e Qabus	PV (2), Batt (15)	13297	0.678	93	0.639
Iranshahr	PV (2), Batt (11)	12012	0.612	99	0.570
Jahrom	PV (2), Batt (11)	12028	0.613	98	0.571
Jask	PV (2), Batt (11)	11572	0.590	76	0.546
Jiroft	PV (2), Batt (11)	12116	0.618	98	0.575

Kamyaran	PV (2), Batt (11)	12327	0.628	96	0.587
Kangan	PV (2), Batt (11)	12021	0.613	98	0.570
Karaj	PV (2), Batt (11)	12455	0.635	95	0.593
Kashan	PV (2), Batt (12)	12451	0.635	96	0.593
Kashmar	PV (2), Batt (12)	12516	0.638	96	0.597
Kazerun	PV (2), Batt (11)	12141	0.619	97	0.577
Khalkhal	WT (1), Batt (11)	12421	0.633	87	0.592
Khash	PV (2), Batt (11)	12129	0.618	98	0.576
Khomeyn	PV (2), Batt (11)	12259	0.625	96	0.583
Khormuj	PV (2), Batt (11)	12142	0.619	97	0.577
Khoy	PV (2), Batt (14)	12762	0.651	96	0.610
Kuhdasht	PV (2), Batt (10)	11900	0.607	98	0.564
Langarud	WT (1), Batt (11)	13435	0.685	80	0.646
Lar	PV (2), Batt (13)	12383	0.631	98	0.590
Ilam	PV (2), Batt (11)	12496	0.637	94	0.596
Gorgan	PV (2), Batt (14)	13129	0.669	93	0.630
Hamedan	PV (2), Batt (11)	12185	0.621	97	0.579
Kerman	PV (2), Batt (11)	12056	0.615	98	0.572
Kermanshah	PV (2), Batt (14)	12824	0.654	95	0.613
Khoramabad	PV (2), Batt (11)	12149	0.619	97	0.577
Mashhad	PV (2), Batt (13)	12779	0.652	95	0.611
Mahabad	PV (2), Batt (15)	13065	0.666	95	0.626
Maragheh	PV (2), Batt (12)	12664	0.646	94	0.605
Marand	PV (2), Batt (13)	12572	0.641	96	0.600
Marivan	PV (2), Batt (12)	12406	0.633	96	0.591
Masjed-e Soleyman	PV (2), Batt (11)	12309	0.628	96	0.586
Mianeh	PV (2), Batt (13)	12730	0.649	95	0.608
Minab	PV (2), Batt (11)	12116	0.618	98	0.575
Naiin	PV (2), Batt (10)	11881	0.606	98	0.563
Neyriz	PV (2), Batt (10)	11994	0.611	97	0.569
Neyshabur	PV (2), Batt (12)	12537	0.639	96	0.598
Esfahan	PV (2), Batt (10)	11985	0.611	98	0.568
Orumeih	PV (2), Batt (11)	12564	0.641	94	0.599
Parsabad	PV (0), Batt (10)	11614	0.592	92	0.548
Qaen	PV (2), Batt (11)	12199	0.622	97	0.580
Qom	PV (2), Batt (11)	12325	0.628	96	0.587
Ramsar	PV (2), Batt (12)	12590	0.642	95	0.601
Ravar	PV (2), Batt (10)	12018	0.613	98	0.570
Sanandaj	PV (2), Batt (12)	12465	0.636	96	0.594
Sabzevar	PV (2), Batt (12)	12448	0.635	96	0.593
Saravan	PV (2), Batt (11)	12116	0.618	98	0.575
Sari	PV (2), Batt (15)	12718	0.648	98	0.608
Semnan	PV (2), Batt (11)	12336	0.629	96	0.587
Shahr-e kord	PV (2), Batt (11)	12380	0.631	96	0.589
Shiraz	PV (2), Batt (10)	11991	0.611	98	0.569
Sepidan	PV (2), Batt (11)	12093	0.617	98	0.574
Shar-e Babak	PV (2), Batt (10)	12005	0.612	98	0.569

Shahroud	PV (2), Batt (11)	12299	0.627	96	0.585
Sirjan	PV (2), Batt (11)	12039	0.614	99	0.571
Tabriz	PV (2), Batt (11)	13139	0.670	89	0.630
Tehran	PV (2), Batt (12)	12542	0.639	95	0.598
Tabas	PV (2), Batt (11)	12061	0.615	98	0.572
Takab	PV (2), Batt (11)	12322	0.628	96	0.586
Taybad	PV (2), Batt (11)	12445	0.634	95	0.593
Torbat-e jam	PV (2), Batt (12)	12657	0.645	95	0.604
Torbat- Heydarieh	PV (2), Batt (11)	12501	0.637	95	0.596
Yasuj	PV (2), Batt (11)	12138	0.619	97	0.576
Yazd	PV (2), Batt (11)	12295	0.627	96	0.585
Zahedan	PV (2), Batt (11)	12157	0.620	98	0.578
Zabol	PV (2), Batt (11)	12195	0.622	98	0.580
Zanjan	PV (2), Batt (12)	12328	0.629	97	0.587

The highest electricity cost among all the stations under study is 0.78 $/kWh, which is based on the total net present cost of $ 14669 for Darab station.

The average amount of electricity price and the total net present cost of the 102 stations under study to provide an electric load of 5.9 kWh/day with a peak of 806 W are 0.63 $/kWh and $ 12415, respectively. The percentage of use of renewable energy in the studied stations ranges between 76 % (Jask) to 99 % (Ardakan, Bushehr, Dir, Iranshahr and Sirjan). Therefore, the use of 1 kW diesel generator is required at all stations. The average use of renewable energy for all stations is 95.3 %. In addition, for the stations under study, on average, if the distance from the national grid is more than 593 m, the use of the hybrid renewable energy system will be cost-effective.

Figures 7 and 8 show the average monthly electricity production for Darab and Bandarabbas stations, respectively. As shown in Figure 7, Darab Station experienced a serious need for diesel generator in March; in July, all the required electricity was provided by solar cells. In addition, from the total of 3072 kWh of electricity produced during the year at Darab Station, 86 % of which is supplied by solar cells, there will be about 13.1 % of excess electricity.

As shown in Figure 8 for Bandarabbas, in January, February, June, July, and September, a wind turbine was able to provide all the required electricity, and the most serious need for the diesel generator occurred in March and December. In Bandarabbas, a total of 3766 kWh of electricity is produced during the year, 96 % of which is produced by wind turbines. In Bandarabbas, there will be 32.5 % of excess electricity, which could reduce the price per kWh of produced electricity by selling it to the national electricity grid.

The important result of Table 3 is the absolute superiority of the solar-diesel generator system to the wind turbine-diesel generator system. As a result, at 4 stations in Ahar, Bandarabbas, Khalkhal, and Langarud, the wind turbine system is economically preferable to solar cell systems; however, in other stations, the solar cell system is preferable.

According to the results of Table 3, the most suitable wind turbine system, which is the most suitable renewable energy hybrid system, is related to Bandarabbas station, while the most appropriate solar cell-based system with $ 0.59 cost per kWh of electricity production is related to Jask Station with a total net present cost of $ 11572.

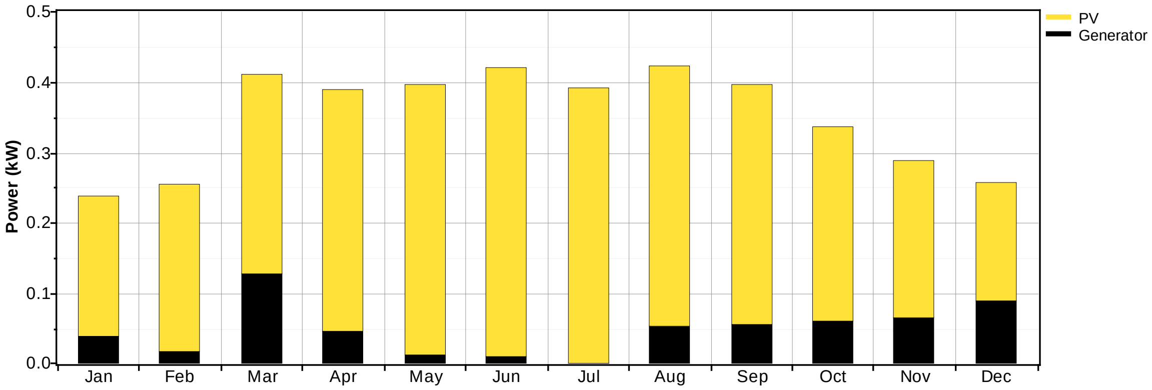


Figure 7. Monthly average of electricity production for Darab station.

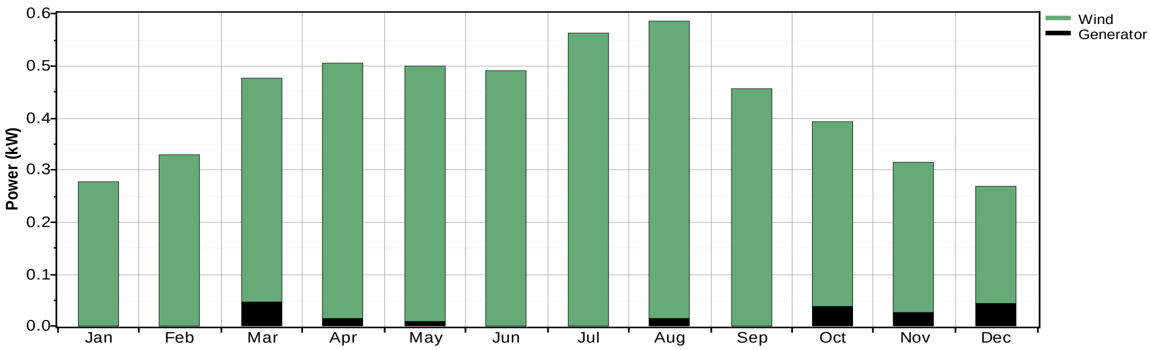


Figure 8. Monthly average of electricity production for Bandarabbas station.

Figure 9 shows the cumulative distribution of the wind speed for Darab and Bandarabbas stations. The Weibull plot is in good agreement with the measured speed, which is represented by a normalized bar graph. As it could be seen in Figure 9, wind speeds equal to or higher than 5.6 m/s which are regarded as good or excellent in terms of wind potential each are associated with wind speed frequencies of 31.9 and 51.3 percent for Darab and Bandarabbas stations, respectively. In addition, given the red line in Figure 9 which is obtained by fitting to wind speed experimental data, parameters c and k of 5.15 m/s and 1.97 for Darab and 6.79 and 1.99 for Bandarabbas stations were obtained, respectively.

As observed in Figures 10 and 11, for Darab and Bandarabbas stations, wind speed is higher than 4 m/s for 54.6 and 70.6 percents of wind availability hours, respectively. In addition, availability hours for 4 to 20 m/s wind speeds, which are the cut-in and cut-out speeds of most wind turbines, are 4769 and 6183 h/y for these stations, respectively. Windheim defines the economic performance of wind turbines as minimum operation for 4000 hours and a useful life of 20 years [26]. Thus, according to Windheim's criteria, the use of wind energy will be cost-effective for Darab and Bandarabbas stations.

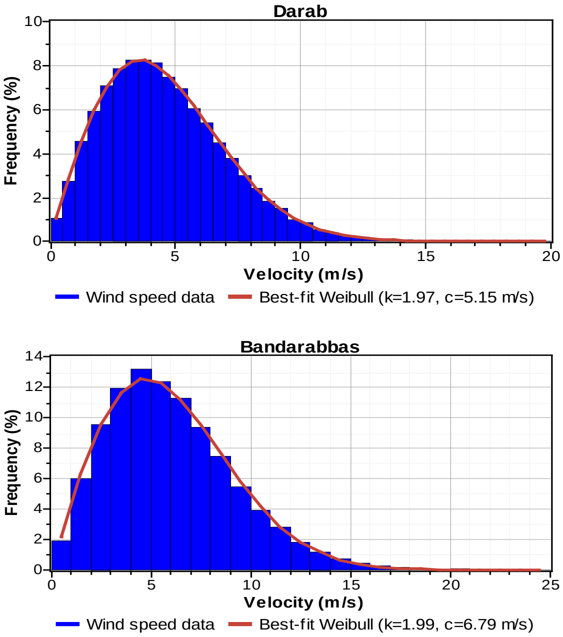


Figure 9. Wind speed Weibull function.

Results of evaluating the turbulence intensity parameter are presented in Table 4. From the results, it is clear that Ahvaz, Abadan, Arak, Alvand, Ardestan, Bandarabbas, Bojnord, Do Rud, Gonabad, Iranshahr, Karaj, Kashan, Khomeyn, Khoy, Hamedan, Kerman, Kermanshah, Marivan, Parsabad, Qaen, Qom, Sanandaj, Sabzevar, Shiraz, Taybad, Zahedan, and Zabol stations have a medium level of turbulence (0.1-0.25), while Ahar, Bukan, Birjand, Khalkhal, Mashhad, Mahabad, Maragheh, Mianeh, Shahroud, Tabriz, Tehran, Takab, Torbat-Heydarieh, and Yazd stations have a high level of turbulence (more than 0.25). This means that the mechanical components of wind turbines at the aforementioned stations have been under medium and high levels of fatigue load, respectively. The lowest and highest values for turbulence intensity parameter are obtained for Tabriz (0.668) and Ramsar (0.006) stations. The average value of turbulence intensity parameter for all stations is 0.127.

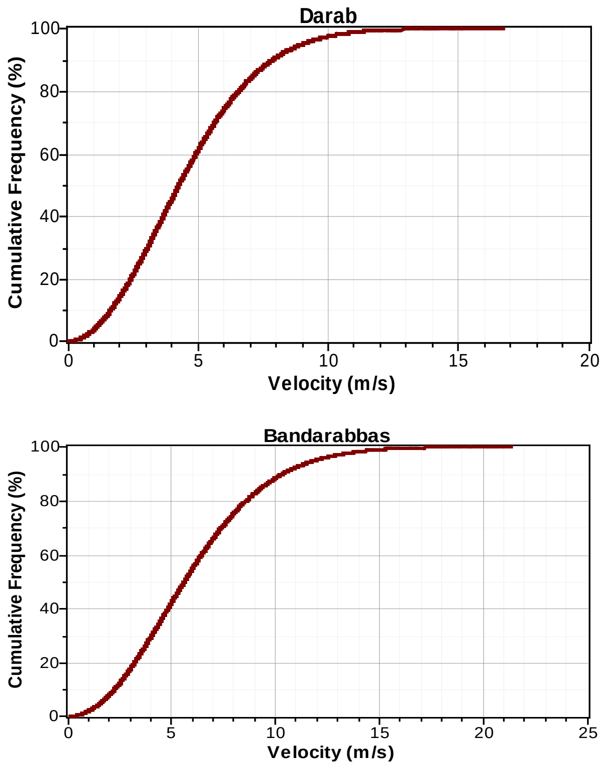


Figure 10. Annual wind speed cumulative distribution function.

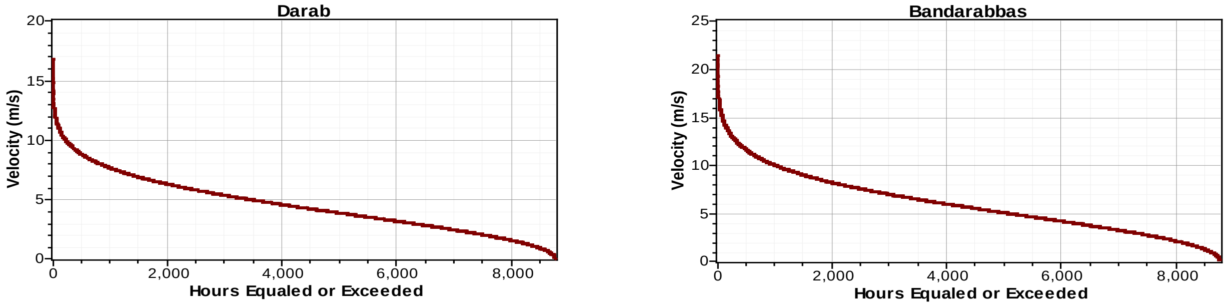


Figure 11. Wind continuity-wind speed curve.

Table 4. Turbulence Intensity for studied stations.

Station	TI	Station	TI	Station	TI
Ahwaz	0.151	Garmsar	0.058	Minab	0.049
Abadan	0.228	Gonabad	0.110	Naiin	0.094
Abadeh	0.075	Gonbad-e Qabus	0.030	Neyriz	0.035
Ahar	0.461	Iranshahr	0.184	Neyshabur	0.036
Arak	0.164	Jahrom	0.025	Esfahan	0.071
Alvand	0.202	Jask	0.035	Orumeih	0.052
Anzali	0.020	Jiroft	0.063	Parsabad	0.161
Aq Qaleh	0.013	Kamyaran	0.069	Qaen	0.199
Ardakan	0.089	Kangan	0.026	Qom	0.207
Ardestan	0.144	Karaj	0.222	Ramsar	0.006
Babol	0.025	Kashan	0.142	Ravar	0.087
Bafq	0.068	Kashmar	0.047	Sanandaj	0.210
Baft	0.059	Kazerun	0.031	Sabzevar	0.229
Bam	0.095	Khalkhal	0.275	Saravan	0.034
Babolsar	0.041	Khash	0.038	Sari	0.027
Bandar-e Genaveh	0.029	Khomeyn	0.141	Semnan	0.053
Bandar-e Lengeh	0.039	Khormuj	0.032	Shahr-e kord	0.055
Bandar-e Mahshahr	0.032	Khoy	0.105	Shiraz	0.196
Borujen	0.042	Kuhdasht	0.028	Sepidan	0.045
Bukan	0.320	Langarud	0.017	Shar-e Babak	0.056
Bandarabbas	0.151	Lar	0.029	Shahroud	0.275
Birjand	0.473	Ilam	0.031	Sirjan	0.044
Bojnord	0.194	Gorgan	0.025	Tabriz	0.668
Bushehr	0.038	Hamedan	0.170	Tehran	0.333
Chabahar	0.098	Kerman	0.134	Tabas	0.099
Chalus	0.059	Kermanshah	0.136	Takab	0.394
Darab	0.029	Khoramabad	0.062	Taybad	0.176
Dargaz	0.027	Mashhad	0.324	Torbat-e jam	0.072
Dehloran	0.046	Mahabad	0.263	Torbat-Heydarieh	0.510
Dezful	0.044	Maragheh	0.350	Yasuj	0.034
Dir	0.033	Marand	0.098	Yazd	0.272
Do Gonbadan	0.029	Marivan	0.219	Zahedan	0.168
Do Rud	0.120	Masjed-e Soleyman	0.024	Zabol	0.175
Firuzabad	0.025	Mianeh	0.570	Zanjan	0.026

Figure 12 shows a comparison between development of the national power grid and construction of a renewable system. Based on the diagrams, it is obvious that by increasing the distance from the national grid, a linear increase in the cabling and maintenance prices occurs, while the costs of constructing renewable systems are fixed and are not dependent on the distance from the national grid. For Darab and Bandarabbas stations, as it is seen in Figure 12, in distances respectively farther than 712 m and 536 m, the price of renewable system (orange line) is lower than that of developing the national power grid (blue line), which is vice versa for shorter distances.

6. CONCLUSIONS

Low-cost electricity has also made creation of renewable power plants non-economical. Of course, for the distances away from the national grid, based on the high cost of cabling and operating & maintenance of the power grid, the use of an off-grid renewable energy system is economical. Therefore, in the present work, by using commercial software HOMER, 102 stations in Iran were examined in order to find the optimal distance to the national grid for the cost-effective use of renewable energy. The main results as follows:

- Bandarabbas and Darab are the most suitable and unsuitable stations in Iran for using the renewable energy hybrid system.
- In Bandarabbas and Darab, the minimum distance from the national grid for the cost-effectiveness of the use of renewable energy is 536 m and 712 m, respectively, which is the lowest and the highest among 102 stations.
- The lowest and highest electricity prices among all under study stations are 0.58 $/kWh (Bandarabbas) and 0.78 $/kWh (Darab).
- For the 102 stations under study, the average amount of electricity price, the average total net present cost, and the average consumption of renewable energy are 0.63 $/kWh, $ 12415, and 95.3 %, respectively.
- The percentage of using renewable energy in these stations is between 76 % (Jask) to 99 % (Ardakan, Bushehr, Dir, Iranshahr, and Sirjan). Therefore, the use of 1 kW diesel generator is required at all stations.
- At Ahar, Bandarabbas, Khalkhal, and Langarud stations, the wind turbine system is economically preferable to the solar cell system; however, at other stations, the solar cell system is preferable.
- The most suitable wind turbine system, as the most suitable renewable energy hybrid system, and the most suitable solar cell-based system are related to Bandarabbas and Jask, respectively.

7. ACKNOWLEDGEMENT

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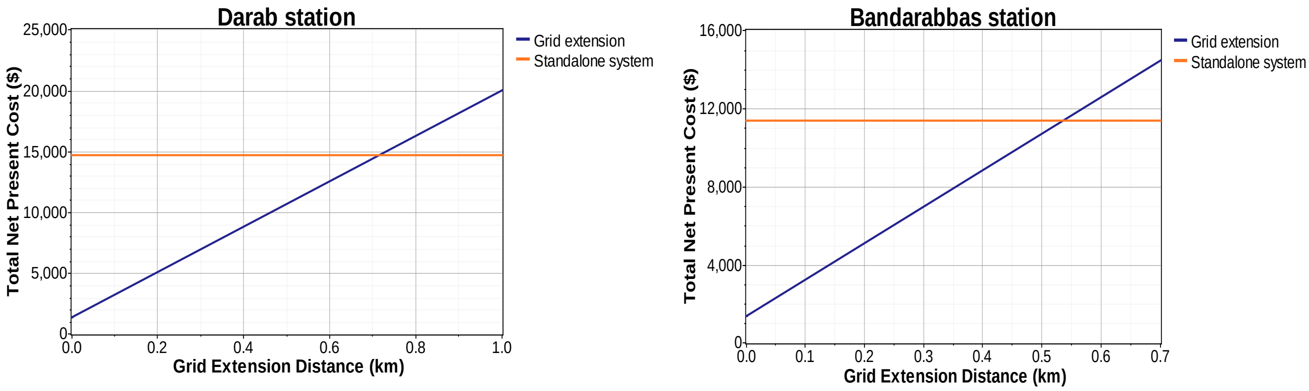

Figure 12. Distance from the national grid in terms of cost.

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