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Research Article

Designing and Sensitivity Analysis of an Off-Grid Hybrid Wind-Solar Power Plant with Diesel Generator and Battery Backup for the Rural Area in Iran

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Because of the lack of transmission and distribution grid of electricity in remote and inaccessible areas due to the high cost of construction of the transmission line along with the unsuitable geographical conditions and taking into account the factors affecting sustainable energy production, renewable energy seems like a sensible solution. Therefore, in this paper, considering the solar and wind potential of Turkalan village located in East Azerbaijan Province, the combined solar-wind-diesel generator system with battery bank and independent of the grid was evaluated. Sensitivity analysis and optimal measurement of the studied system were performed by HOMER software. Sensitivity analysis was performed on the parameters of solar radiation, light reflection from the environment, and wind speed. The goal was to supply 22 kWh/d of energy with a maximum load demand of 2.5 kW. The four hybrid systems proposed by the software considering the total net present cost (NPC) were solar-generator-battery, solar-wind-generator-battery, solar-battery, and solar-wind-battery, respectively. The studies were conducted to determine which of the systems is more suitable for the area.

1. Introduction

Today, the use of renewable resources is on the agenda of many countries around the world, and an important investment process in the world is being developed in dispersed products. Regarding environmental issues and global warming, the use of these renewable energies has become necessary in the past [1–3]. By 2016, worldwide electricity generation from fossil fuels and renewable resources is 75.5% and 24.5%, respectively, of which energy produced by countries of China, America, Brazil, Germany, and Canada is superior in this area [4–6]. Renewable energy use is an alternative to fossil power plants due to its easy access and the renewable energy structure, lack of transmission and distribution network in remote areas due to the high cost of construction of the transmission line along with the inadequacy of the geographical conditions, and taking into account the factors affecting the sustainable energy production. The use of an independent grid system is a convenient option to meet the need to use electricity [7–9]. Over the years, researchers have been struggling to address the weakness of renewable resources by concentrating on the use of these resources combined with overcoming the weakness of these resources, making progress on the use of these distributed resources independently of the network or connected to the network [10–13]. However, in the design of dispersed production systems, it has combined challenges such as energy management, due to the intermittent nature of renewable resources and the diversification of energy demand [14–16], but the need for energy at all times of day and meeting consumer needs in mind getting system reliability due to unstable weather conditions in the area during daylight hours is used to store excess energy at times that require reduced energy consumption and the use of this energy when needed by the storage or battery [17, 18].

The necessity of acquiring accurate region information and the overall view of the design of the system to meet the demands of the year in hybrid systems is crucial for obtaining optimum size [19]. In this context, software such as HOMER and iHOGA can be used to obtain the optimum size and design of the hybrid system [20, 21]. Homer software is provided by the National Energy Laboratory of the United States to design a variety of microgrid systems, connected to the network, isolated from the network, and access to the climate database, with economic evaluation and analysis of the sensitivity of existing parameters, including energy cost and strategy to meet the load and obtain the lowest final cost of the system; and it proposes an optimal solution system for load balancing [22–24]. The disadvantages of software can be high computational time and not able to optimize multiobjectives [25]. In these articles, a general review is provided using this software for optimal combination programming. Research findings [26] analyze the cost of wind and solar hybrid systems with access to solar and wind resources in a region of Georgia, based on a combination of the independent network of wind and solar power plants and considering the life span of 25 years for the design project. Also in referring [27] has used a 5 kW microturbine in Nigeria to meet the design needs of the project. Combined systems are typically designed from two or more dispersed generation sources such as biomass, the geothermal, wind, solar, and microturbine water with a backup source for energy access throughout the hours. In the meantime, the use of solar and wind combinations has been of particular interest in many parts of the world [28]. The use of batteries or power grids is for easy access to energy at times when the production of energy from renewable sources due to climate change in the region's climate increases the reliability of the system. In the latest research, hydrogen can be used as a high-efficiency source compared to batteries [29].

The selection of each component of the hybrid power plant considers the climate and geography of the region depending on the needs of the consumer, considering the costs of construction, exploitation, social and environmental costs, and finally options which have the most favorable economic and environmental conditions than other options. In Figure 1, a hybrid system is shown.

The purpose of this study is to find the annual electricity production of the microgrid system and the optimal capacity of system components and compare between different modes. From the types of equipment, the most economical type of combination is selected, and finally, the net profit of the whole system, which is calculated according to the net present cost method, is expressed along with the relevant analyses.

2. Material and Method

Accurate information about the geographical environment is very important for analyzing renewable energy systems. Because renewable energy sources are highly dependent on environmental factors, the intensity of sunlight and wind is a function of time. So, the first step in designing production systems based on renewable sources is to determine renewable energy sources. The most important factor in the use of renewable energy is economic parameters; in this study, HOMER software has been used for this work and determination of economic indicators. Figure 2 shows an overview of the system being designed.

The flowchart of software performance is shown in the figure below. The type and number of inputs required to perform simulation, optimization, and economic ranking calculations are shown in the flowchart. Also, technical-economic-energy-environmental outputs show the high ability of software to analyze issues related to renewable energy.

2.1. Climatic Conditions of Solar Energy. The sun is a massive source of energy that supplies our power to direct and indirect forms and causes natural processes such as the displacement of the air. The Earth's share of energy from the sun is a small amount of total solar radiation. Solar energy can be one of the most important renewable energies for replacing fossil fuels. As a result, this emerging source has become a priority in many countries, such as China, to increase energy production and greater access [2]. Solar energy is converted into electrical energy by no solar cell [19]. Iran is one of the countries with a good potential to invest in this area in terms of geographical location in terms of sunlight. In this study, the rural Turkalan area located near the city of Ahar in East Azerbaijan Shargi Province has been studied. Using the HOMER software, the amount of sunlight in the region studied is shown in Figures 3 and 4.

In the HOMER software, by specifying the area required by latitude and longitude, the average sunlight according to Figure 3 is introduced with the main index. Sensitivity analysis was performed by entering two different indexes of 4 and 5 (kWh/m2/d). Also, in Figure 5, the amount of received sunlight is shown in different months and at different times.

The power produced by solar cells (P_{PV}) is calculated from the following equation by the HOMER software [31]:

$$P_{PV} = Y_{PV} f_{PV} \frac{\overline{G_T}}{\overline{G_{T,STC}}}, \quad (1)$$

where Y_{pv} is the output power of the PV panels in the standard conditions (kW), f_{PV} is the derating factor, $\overline{G_T}$ is the solar radiation received to the collector surface (kW/m^2), and $\overline{G_{T,STC}}$ is the value of $\overline{G_T}$ in the standard conditions (1 kW/m^2). The angle of the solar cells is equal to the latitude of the studied station [31].

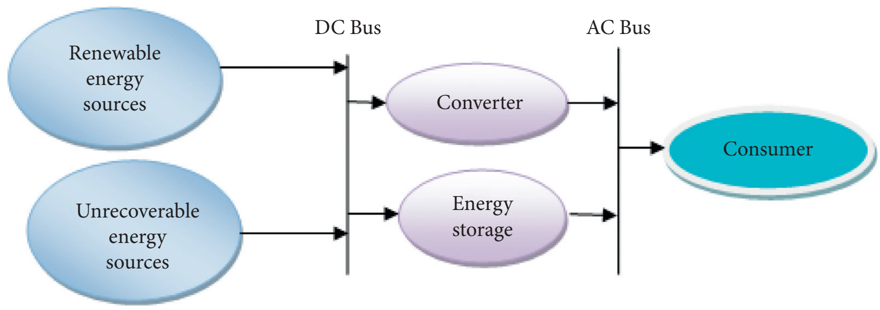

Figure 1: Hybrid system model.

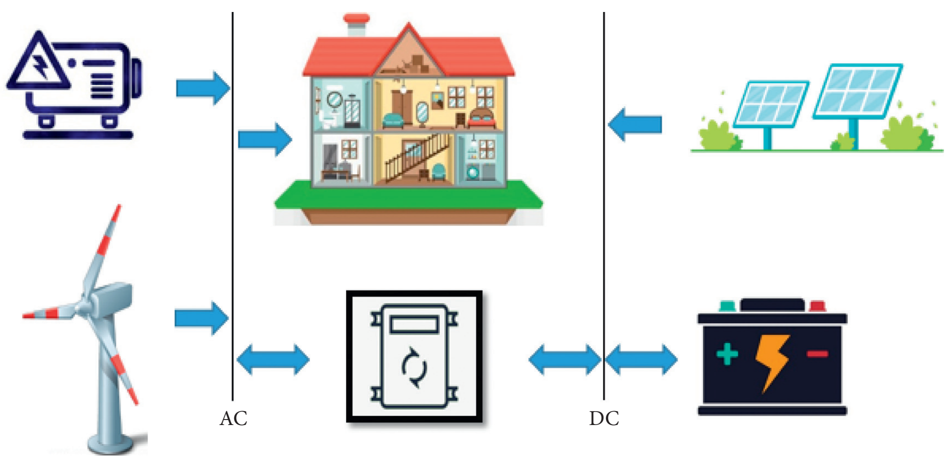

Figure 2: Energy systems based on wind turbines and photovoltaic cells.

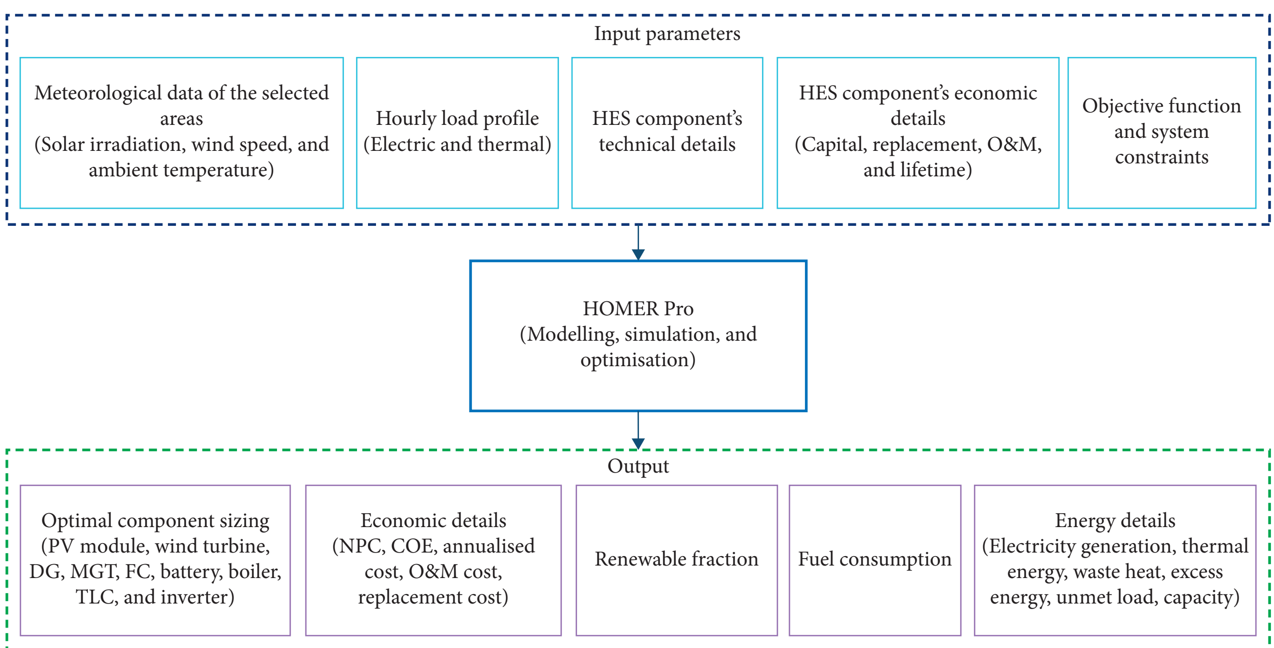

Figure 3: Flowchart of HOMER software performance [30].

2.2. Wind Energy. Because of the different rays of the sun in different latitudes, the surface of the rugged terrain causes changes in temperature and pressure, resulting in a wind blowing. Often, the nature of wind energy is oscillating and intermittent and does not have a definite time for constant heat. The disadvantages of wind energy can be attributed to

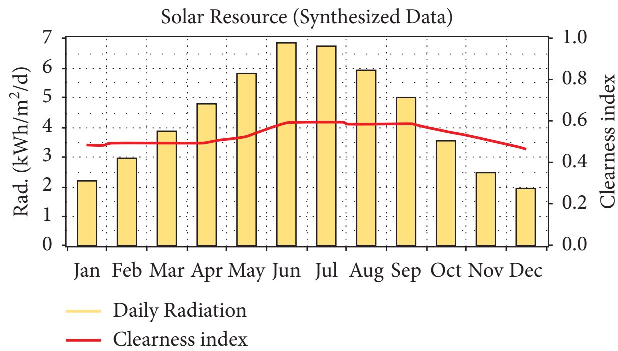

Figure 4: The amount of solar radiation in the Turkalan area.

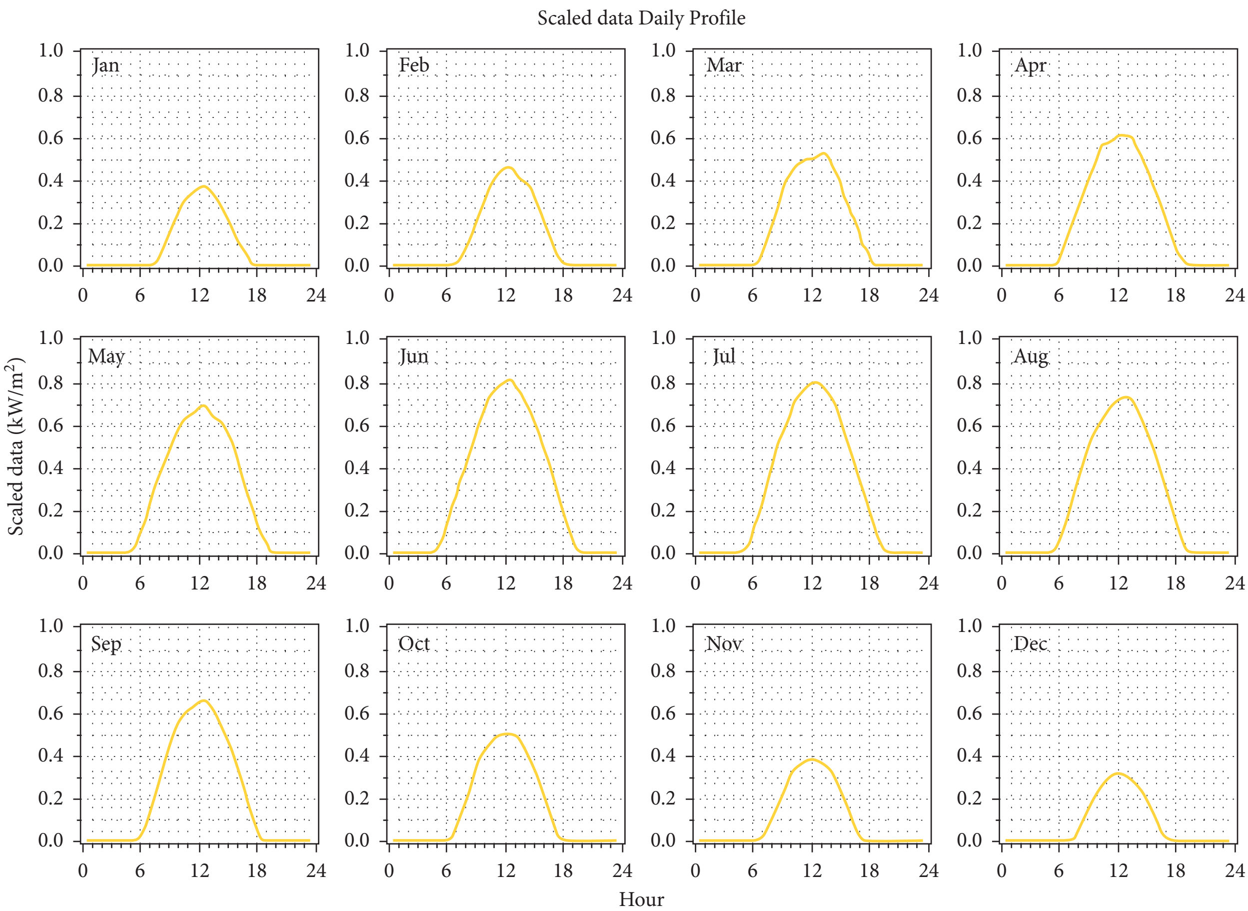

Figure 5: Annual Profile of Sun Radiation in the Turkalan Area (kW/m^2).

the variability of production at different times and low reliability [20]. To obtain the wind speed in the area, using the Meteororm software, wind speed information is obtained according to Figures 6 and 7. Despite environmental factors such as ripples affecting wind speed, various wind speeds of 2.5 m/s and 4 were used for the assessment and analysis of sensitivity [32].

The output power of a wind turbine depends on its altitude [33]. The output power of wind turbine is calculated by the following equation by the HOMER software [34]:

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

where ρ is the air density in real conditions, ρ_0 is the air density in standard conditions, and $P_{WTG,\,STP}$ is the output power (kW) which is obtained from the turbine power curve.

Wind turbines are used to generate electricity, while small wind turbines have been used to save costs. These types of turbines have low-diameter rotors, which are intended here on the consumer side to charge the batteries. The cost of

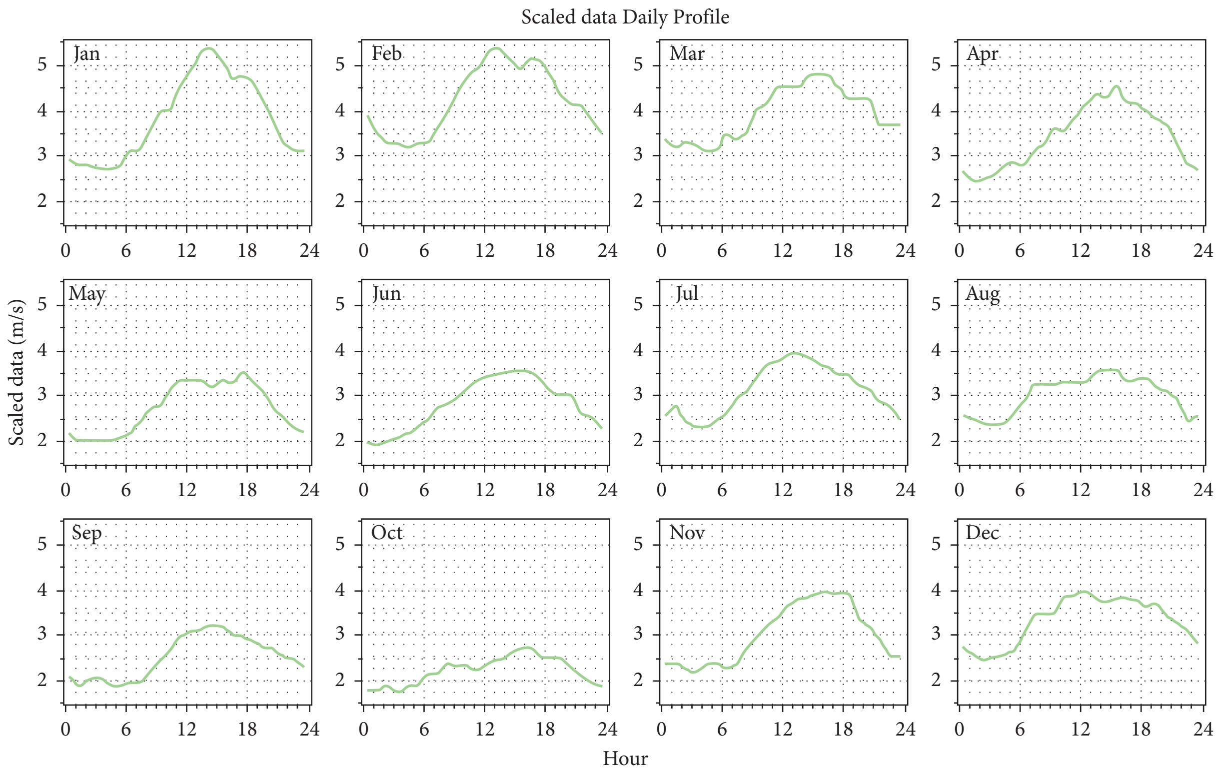

Figure 6: Wind profile in different months in the Turkalan area.

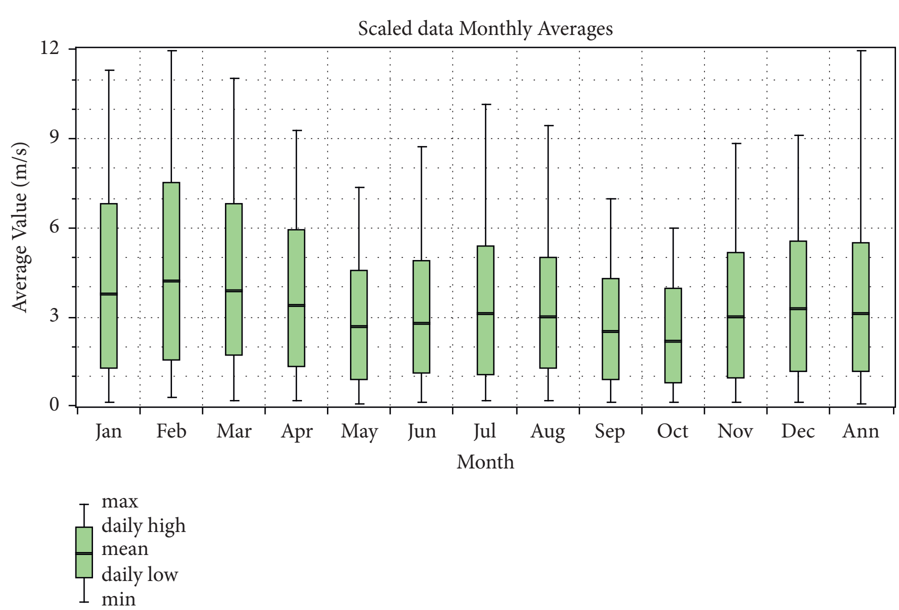

Figure 7: Wind speed in different months in the Turkalan area.

a one-kilowatt turbine with a life span is 1,200 $, the cost of replacement and repairs and maintenance for the year is 770 $ and 10 $/yr, respectively, and the production characteristic curve is shown in Figure 8.

2.3. System Configuration, Operation, and Optimization. In this system, photovoltaic unit and wind turbine are present as renewable energy sources, diesel generator as support for power generation, and batteries to store excess

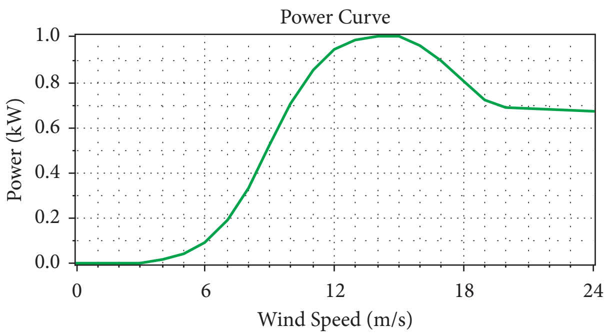

Figure 8: Wind turbine production characteristic curve.

energy and improve system reliability. In some systems, a storage system (battery bank) is used when the power generated by renewable energy sources (P_{re}) at time t is not sufficient to supply the power load (P_l). If the load demand is high and the energy storage system is not able to supply this total energy, the diesel generator intervenes to meet the remaining load demand. This mechanism is based on the following three steps:

(1) First step: If it is $P_{rs}(t)<P_l(t)$, the third step should be done. Otherwise, the second step is done.

(2) Second step: Set the battery bank charge to $t=t+1$ and then perform the first step.

(3) Discharge the battery bank. If it is $SOC < SOC_{min}$, the diesel generator will start; otherwise, the time will be set to $t=t+1$ and then the first step will be done.

The output power of each photovoltaic system (P_{PV}) at moment t can be calculated based on the following relation of solar radiation:

$$p_{PV}(t) = I(t) \times A \times \eta_{PV}. \tag{3}$$

In this regard, I is solar radiation, A is the cross section of the photovoltaic system, and η_{PV} is the total efficiency of the photovoltaic system panels and the DC/DC converter.

For a wind turbine, if the given wind speed exceeds the cutoff value, the wind turbine will start producing. If the wind speed exceeds the nominal value of the wind turbine speed, the turbine will start producing a constant amount of output power. If the wind speed exceeds the high cutoff value, the wind turbine generator will stop to protect the turbine. The output power of each wind turbine (P_{WT}) at moment t is as follows:

$$p_{WT}(t) = \begin{cases} 0, & v(t) \le v_{\text{cut-in}} \text{ or } v(t) \ge v_{\text{cut-out}}, \\ P_r \dfrac{v(t) - v_{\text{cut-in}}}{v_r - v_{\text{cut-}o<\tau}}, & v_{\text{cut-in}} \le v(t) \le v_r, \\ P_r, & v_r < V(t) < v_{\text{cut-out}}. \end{cases} \tag{4}$$

In this regard, v is wind speed, P_r is nominal wind turbine powers, $v_{\text{cut-in}}$ is low wind turbine cutoff speeds, $v_{\text{cut-out}}$ is high wind turbine cutoff speeds, and v_r is nominal wind turbine speeds.

As a backup power system, the diesel generator will start operating when the power output is insufficient and the power level of the energy storage system is low. In this case, the diesel generator starts working and compensates for the power shortage.

Diesel generator $\text{Cons}_D = (1/h)$ fuel consumption depends on the output power and is defined as follows:

$$\text{Cons}_D = B_D \times P_N^D + A_D \times P_D. \tag{5}$$

In this regard, P_N^D is the nominal power, P_D is the output power of the diesel generator, and two are the parameters BD and AD of the fuel curve coefficients, which are defined as BD = 0.0845(l/kWh) and AD = 0.246(l/kWh).

The hourly cost of fuel consumption can be obtained as follows:

$$C_f = P_{fuel} \times \text{Cons}_D, \tag{6}$$

P_{fuel} is the cost of fuel.

Due to the variable behavior of photovoltaic panels and wind turbines, the capacity of the battery bank in the hybrid system is constantly changing. On some systems, the battery charge mode can be achieved as follows:

When the output power of photovoltaic panels and wind generators exceeds the load energy, the battery bank will be in the charging position.

$$E_{\text{Batt}}(t) = E_{\text{Batt}}(t-1) \times (1-\sigma) + \left[\left(E_{PV}(t) + \left(E_{Wt}(t)\right) - \frac{E_{\text{load}}}{\eta_{Inv}}\right)\right] \times \eta_{\text{Batt}}. \tag{7}$$

$E_{\text{Batt}}(t)$ and $E_{\text{Batt}}(t-1)$ are the amount of battery charge in moments t and t-1, respectively, σ hourly self-discharge rate, η_{Inv} inverter efficiencies, E_{load} load demand, and η_{Batt} battery bank charge efficiencies.

2.4. Other Equipment and Financial Calculation. The battery in order to save energy and deliver the energy required in different situations, the battery bank in the system is considered. Regarding the types of models available in the software, the vision model 6FM200D with characteristic (200 Ampere, 12V, 917 kWh) is reviewed at HOMER. The cost of the used battery is 287 $, and the replacement and maintenance costs are 266 $ and 1 $/yr, respectively.

For limited use of diesel generators, increasing fuel costs and limiting the supply of diesel fuel, it is therefore emphasized that renewable energy can be used as much as possible. The generator price in this analysis is 164 $/kW, and replacement and maintenance costs are 131 $ and 0.001 $/hr, respectively.

Converter power is needed to communicate between the consumer and the power generator. For a 1 kW system with 90% efficiency and a life span of 15 years, the cost of installation and replacement is 300 $ and 249 $, respectively. The intended consumer in this design is considered the domestic load of 22 kWh/d with a maximum load power requirement of 2.5 kW.

$$\eta_{gen} = \frac{3.6\,P_{gen}}{\dot{m}_{fuel}\,LHV_{fuel}}, \tag{8}$$

where P_{gen} is the total electricity produced by generator (kWh/y), $\dot{m}_{fuel}$ is the total fuel consumption (kg/y), and LHV_{fuel} is the low heating value of the fuel (MJ/kg).

The generator efficiency is calculated by the following equation by HOMER software [35].

HOMER software presents a list of classified systems based on the total NPC which is calculated by the following equation [36]:

$$NPC = \frac{C_{ann,total}}{CRF\left(i, R_{proj}\right)}, \tag{9}$$

where $C_{ann,\ total}$ is the total annual cost ($), CRF is the capital recovery factor, i is the real interest rate, and R_{proj} is the project lifetime. The CRF that represents the capital return in N years is calculated by the following equation [37]:

$$CRF = \frac{i\,(1+i)^N}{(1+i)^N - 1} \tag{10}$$

$$i = \frac{i' - f}{1 + f}. \tag{11}$$

The COE in terms of $/kWh during the project lifetime is also calculated by the following equation [38]:

$$COE = \frac{C_{ann,total}}{E_{Load\ Served}}, \tag{12}$$

where E_{Load} Served is the actual electrical charge by the hybrid systems in kWh/y that is priced in dollars.

2.5. Limitations. For photovoltaic-wind-diesel generator-battery system, the following conditions must be met:

$$N_{wind} = \text{Integer}, 0 \le N_{Wind} \le N_{Wind}^{max}, \tag{13}$$

$$N_{PV} = \text{Integer}, 0 \le N_{PV} \le N_{PV}^{max}, \tag{14}$$

$$N_{Batt} = \text{Integer}, 0 \le N_{Batt} \le N_{Batt}^{max}, \tag{15}$$

In these relationships, N_{PV}^{max}, N_{Wind}, and N_{Batt}, respectively, are the most available amount of photovoltaic panels, wind turbines, and batteries.

Limitations for battery model:

Initial battery power SOCintial:

$$soc_t = soc_{initial}. \tag{16}$$

Minimum and maximum energy stored in the battery:

$$\begin{aligned} soc_t &\le soc_{max}, \\ soc_t &\ge soc_{min}. \end{aligned} \tag{17}$$

Minimum and maximum battery charge capacity:

$$\begin{aligned} P_t^{charge} &\le P_{charge}^{max} * U_t^{charge}, \\ P_t^{charge} &\ge P_{charge}^{max} * U_t^{charge}. \end{aligned} \tag{18}$$

Minimum and maximum battery discharge capacity:

$$\begin{aligned} P_t^{discharge} &\le P_{charge}^{max} * U_t^{discharge}, \\ P_t^{discharge} &\ge P_{charge}^{max} * U_t^{discharge}. \end{aligned} \tag{19}$$

The battery cannot be charged or discharged at the same time:

$$U_t^{discharge} + U_t^{discharge} \le 1. \tag{20}$$

Power at any time for the battery:

$$soc_t = soc_{t-1} + \eta_{charge}^{B} * P_t^{charge} - \frac{P_t^{discharge}}{\eta_{discharge}^{B}}. \tag{21}$$

Minimum and maximum diesel power:

$$\begin{aligned} P_t^{D} &\le P_D^{max} * U_t^{D}, \\ P_t^{D} &\ge P_D^{max} * U_t^{D} \end{aligned} \tag{22}$$

3. Results

In Table 1, the cost of the applicable systems along with the optimal equipment sizes is shown by taking into account the analysis of various parameters. The four proposed hybrid systems by the software, taking into account the NPC, are, respectively, solar-generator-battery, solar-wind-generator-battery, solar-battery, and solar-wind-battery. The three wind speed parameters, the amount of sunlight, and the reflection of light from the surface in this analysis have been used as sensitivity variables. To find the optimal HOMER software system, among the various combinations and layouts of the system in the software search space, with an analysis of 8760 hours, all of the possible scenarios for the system are simulated with respect to the required electrical charge, and all the impossible situations deleted to categorize according to the NPC. The optimization results presented in Figures 9–11 give the high potential of using sunlight and relatively low wind speed, and the region of analysis of the amount of sunlight relative to the constant of the other variables. It is possible to use more solar power in different radiation levels around the area in question. According to Table 1, the sensitivity analysis of the system results from the proposal of two systems with accurate weather data, which is the difference between the two systems in the amount of light reflected from the environment. Because of the

Table 1: The effect of changing the intensity of sunlight and wind on the optimal values of the designed system.

Sunlight (kWh/m^2/d)	Wind speed (m/s)	Reflects light from the environment (٪)	Solar panel (kW)	Wind turbine (kW)	Diesel generator (kW)	Battery 200 (Ah)	Converter (kW)	Net present cost (NPC)	Cost of generating energy ($/kWh)
4.032	3.15	20	13	0	2	17	3	27020	371
4.032	3.15	30	13	0	2	17	3	27013	371
4.032	2.5	20	13	0	2	17	3	27020	371
4.032	2.5	30	13	0	2	17	3	27013	371
4.032	4	20	8	1	2	22	3	2342	362
4.032	4	30	8	1	2	22	3	2338	361
4	15.3	20	14	0	2	17	3	27597	379
4	15.3	30	14	0	2	17	3	27588	379
4	5.2	20	14	0	2	17	3	27597	379
4	5.2	30	14	0	2	17	3	27588	379
4	4	20	9	1	2	22	3	2893	369
4	4	30	9	1	2	22	3	26881	369
5	15.3	20	11	0	2	17	3	25877	355
5	15.3	30	9	0	2	22	3	25718	353
5	5.2	20	11	0	2	17	3	25877	355
5	5.2	30	9	0	2	22	3	25718	353
5	4	20	8	1	2	17	3	25383	348
5	4	30	8	1	2	17	3	25373	348

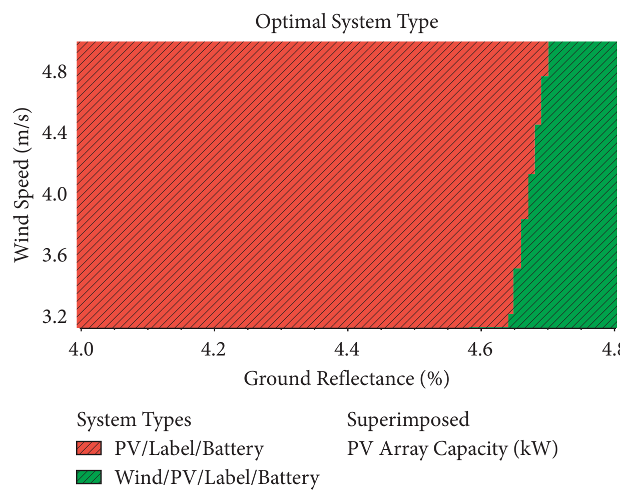

Figure 9: Sensitivity analysis for wind velocity variables and reflection level from surface for constant radiation (5 kWh/m^2/d).

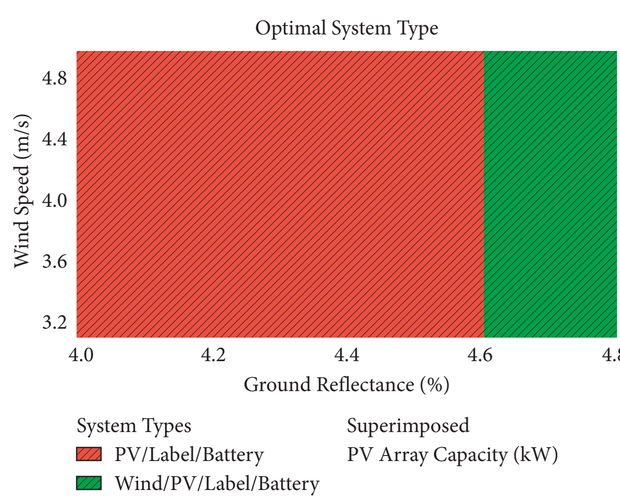

Figure 10: Sensitivity analysis for wind speed variables and reflection level from surface for fixed radiation (32.4 kWh/m2/d).

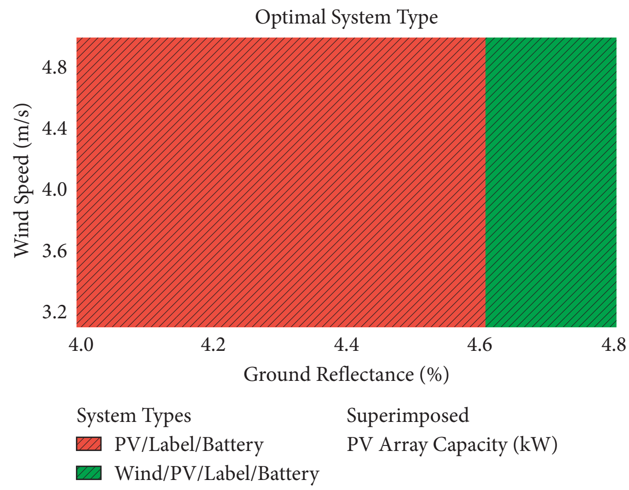

FIGURE 11: Sensitivity analysis for wind speed variables and reflection level from surface for constant radiation (4 kWh/m^2/d).

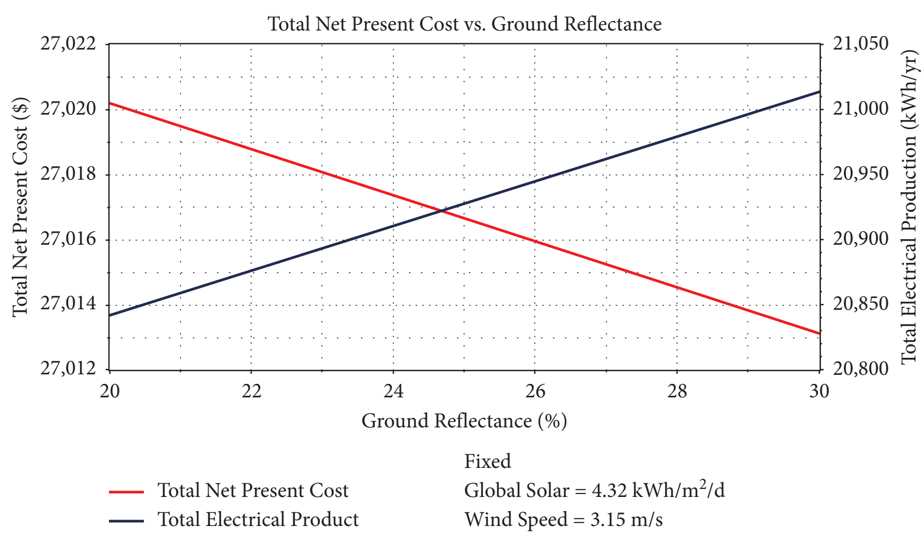

FIGURE 12: Chart of the relationship between the net cost of the system and the system energy production at different percentages of light reflection from the environment.

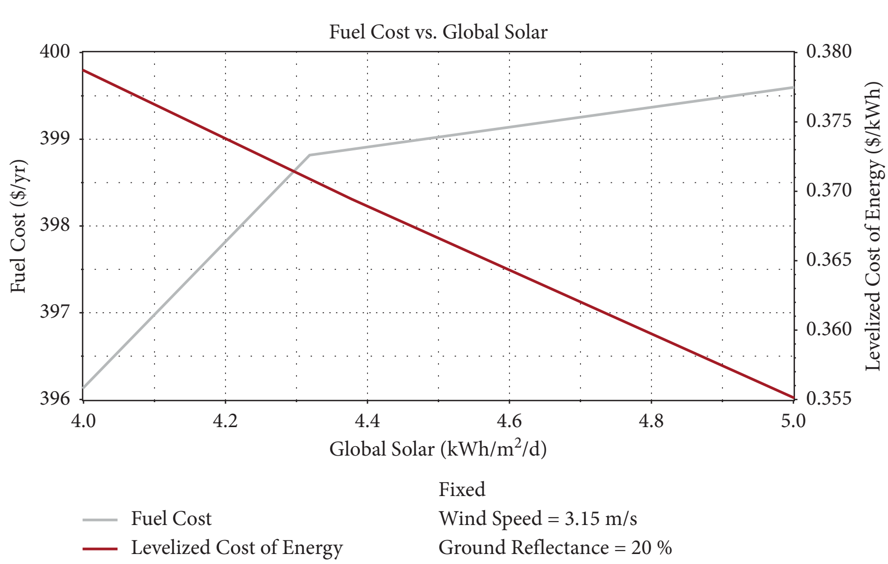

FIGURE 13: Comparison of the cost of diesel fuel with the cost of production by solar panels.

Table 2: Investigation of different scenarios for the studied system.

Combined system	Solar panel (kW)	Wind turbine	Diesel generator (kW)	Battery 200 (Ah)	Converter (kW)	Initial capital ($)	NPC ($)	COE /($) kWh	CO_2 (kg/yr)
Solar-generator-battery	13	0	2	17	3	13582	27020	371	2626
Solar-wind-generator-battery	10	1	2	22	3	14492	2728	379	2607
Solar-battery	14	0	0	50	3	23900	33972	536	0
Solar-wind-battery	13	1	0	50	3	24525	34652	547	0

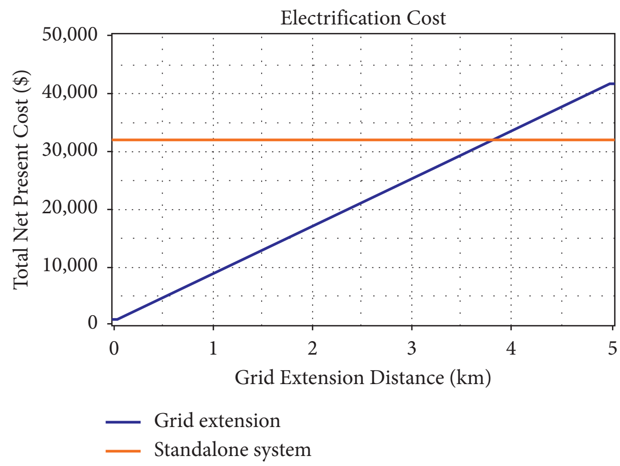

Figure 14: Optimization of system execution distance by comparing construction of transmission line.

Table 3: Optimal specifications of the selected designed system.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	7,475	0	118	0	0	7,593
Generator	328	331	61	3,620	−12	4,328
Vision 6FM200D	4,879	9,185	154	0	−175	14,043
Converter	900	179	0	0	−23	1,056
System	13,582	9,694	334	3,620	−210	27,020

particular climatic conditions in the area, light reflections are considered in the least conditions. Therefore, the system to run in the area with accurate weather data using a solar-diesel combined system with a 20% light reflection battery is an appropriate option for the implementation of the design at the desired location. Considering the villages around the area that are different from the light and wind speed, one can conclude that by increasing the amount of sunlight, the wind speed, and the amount of light reflected from the environment, the final net cost plus cost of energy production is reduced. With the observations in the precise weather data of the software, Figure 12 shows that increasing the amount of light reflections from the environment on the surface of the solar panels has a positive effect, which increases the amount of energy produced and reduces the net system cost. In Figure 13, for comparison of the cost of diesel fuel with the cost of solar panel production, taking into account the amount of light reflection from the environment of 20% and wind speed of 15.3 m/*s*, it is indicated by the variability of the amount of sunlight by increasing the amount of sunlight, energy costs are much lower than diesel fuel. According to Table 2, the cost of generator fuel is estimated at 4 $/L. For the photovoltaic/diesel generator system, which is the battery as an energy storage system, NPC for this system is $ 27020, to supply energy with this system to 13 kW for the solar panel, and 17 batteries are needed. In the grid-connected system, the following grid specifications are considered: 2,500$ per kilometer of transmission line construction, which for this distance is 100$ maintenance costs. In this study, the cost of buying and selling electricity to the grid is estimated at 0.02$. It is economically justified for electricity to run this project at a distance greater than 0.987 km. Figure 14 illustrates the distance between the use of a system independent of the network due to the high cost of construction of transmission lines in difficult areas and out of reach of transmission lines. Table 3 shows the cost of installing, replacing, repairing, and maintaining the system, the cost of fuel, and the cost of the sale of worn-out equipment. As the total cost of the system equipment is 13582 $, the replacement is 9694 $, and the

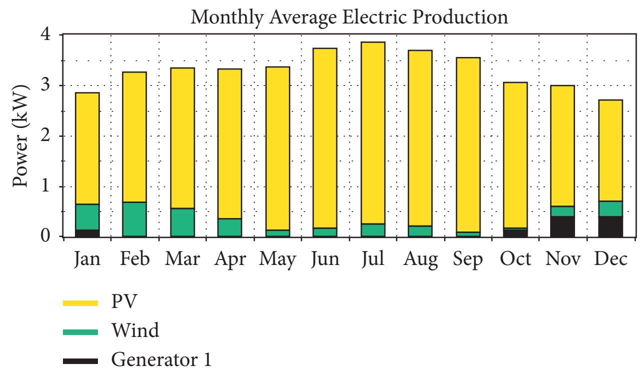

Figure 15: Annual energy production chart.

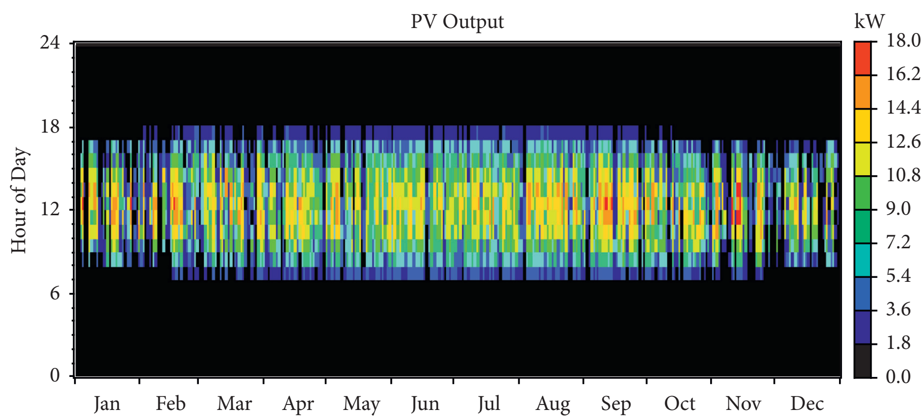

Figure 16: Annual output of solar panel power.

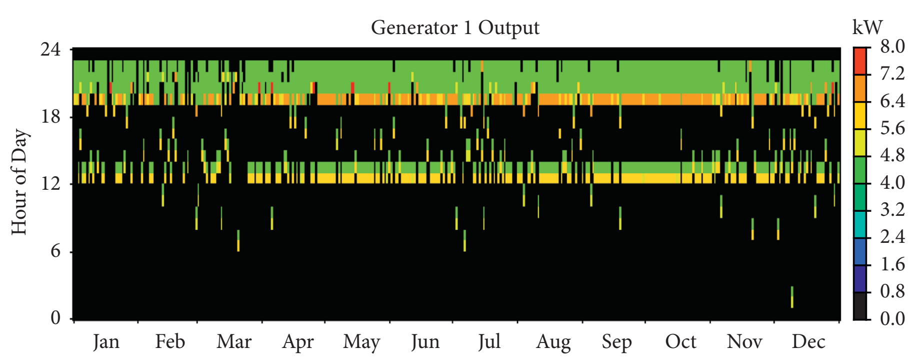

Figure 17: Generator output and annual output.

system repairs and maintenance is 334 $. The amount of energy produced in different months of the year in Figure 15 by solar panels and diesel generators is 89% and 11%, with a power output of 18587 kWh/yr and 2260 kWh/yr, respectively. Figures 16–19 show the output of solar panels and diesel generator at hours of the year. For Turkalan region, according to the solar radiation and wind speed, four models were defined. Due to the solar radiation of high sunlight and low wind speed, the diesel generator model with photovoltaic cell is more suitable. In this model, the cost of each unit of energy produced is 0.371$/kWh, which is much lower than other models.

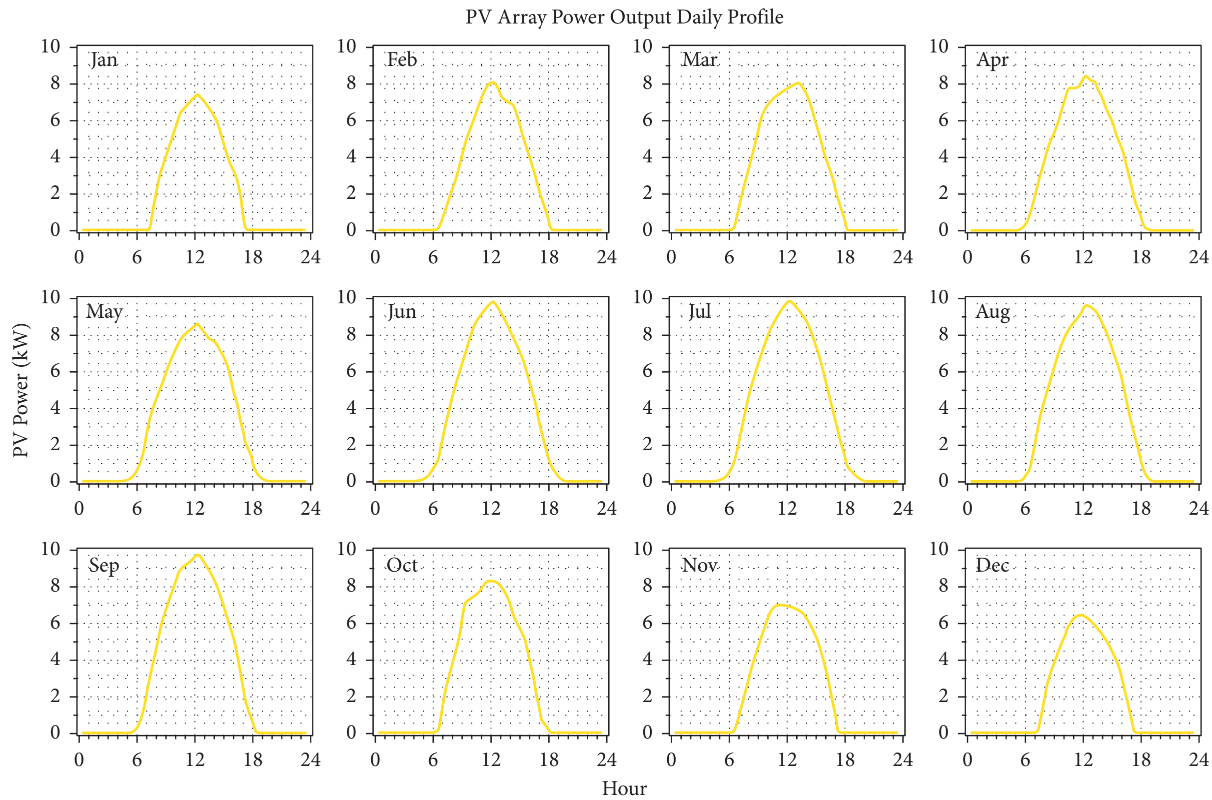

FIGURE 18: Output of the sun's power by months.

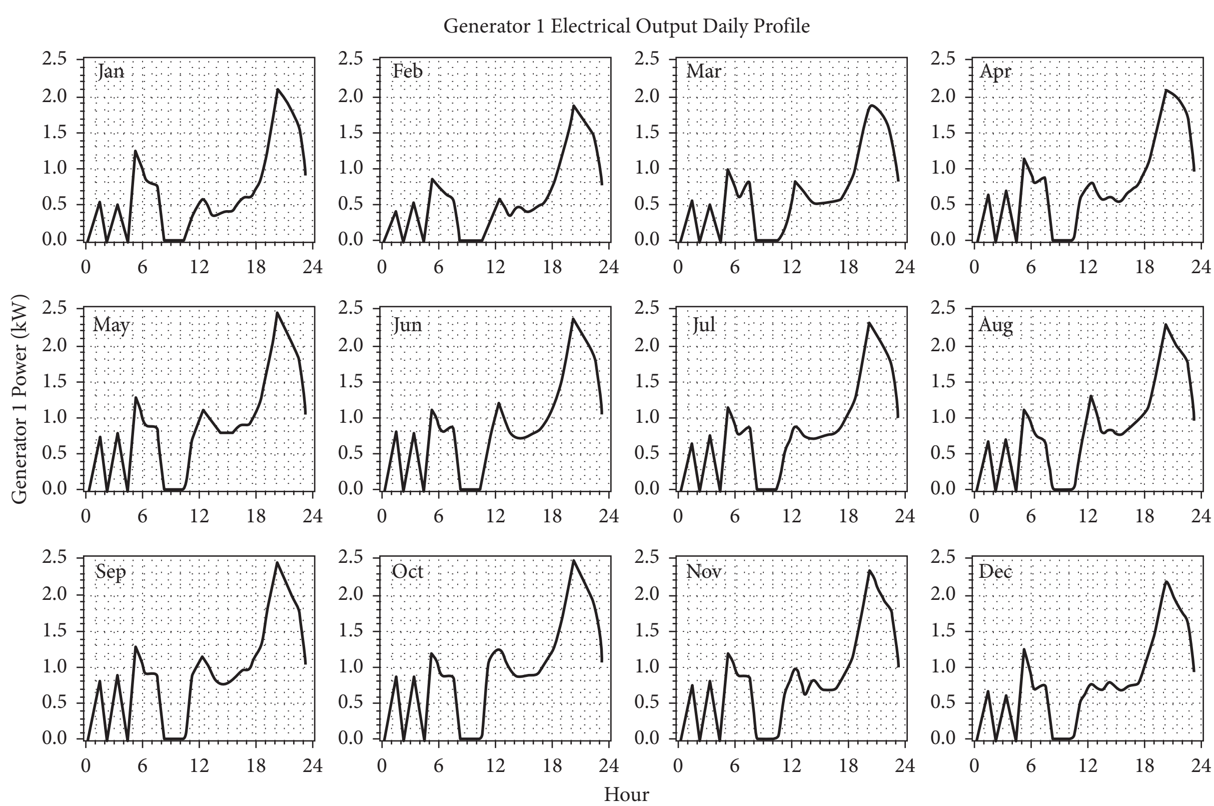

FIGURE 19: Diesel generator power output by month.

4. Conclusion

Due to the lack of energy and the endlessness of renewable energy, new and clean energy has been used in many countries around the world. On the other hand, in remote areas of the grid, independent networks considering the environmental conditions of the region seem to be a sensible solution. Hence, Iran has the potential to use renewable energy as a suitable alternative to fossil fuels. Therefore, in designing the system in HOMER software, the use of hybrid systems has been investigated to improve system reliability and load responses in the Turkalan rural area. In general, due to the increase in the amount of solar radiation, the wind speed, and the reflection coefficient of light from the existing system environment, the net cost is lower than the chosen system. Based on the results obtained from the simulation of the four proposed systems by the software, taking into account the NPC (solar-generator-battery, solar-wind-generator-battery, solar-battery, and solar-wind- battery) with the tests done, the lowest final net cost, respectively, is combined with a solar-generator system with a battery, which has a light reflection coefficient of at least the proportion of other systems at a cost of energy 0.371 $/kWh, and the amount of energy produced by solar panels and diesel generators is 89% and 11%, respectively, and the amount of energy is 18587 kWh/yr and 2260 kWh/yr, respectively, a good solution for supplying the load of the Turkalan area compared to other hybrid systems. The NPC is 3224 $ with a capacity of 13 kW of solar panels and 2 kW of diesel generator with 17 batteries.

Data Availability

All data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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