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Research Article

A case study of PV-wind-diesel-battery hybrid system

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Abstract: A mountain house in Sakarya, Turkey, which is powered by renewable energy resources rather than the conventional ones, has been designed. Therefore, numerous hybrid renewable power generating systems including the components like wind turbine, PV, diesel generator and battery are considered in different configurations. Eventually, they are technically and economically analyzed by using the well-known HOMER software. Furthermore, a sensitivity analysis is also performed considering variations in two important parameters, namely wind speed and solar irradiation. According to the results, the hybrid power generation with the optimal hybrid configuration system includes a 2 kW photovoltaic array, a 1 kW wind turbine, a 1 kW diesel generator, a 1 kW power converter and 12 batteries. In addition, this system has the net present cost of 29,304 $ as well as the cost of energy as 0.752 $/kWh. Lastly, the optimum hybrid system is then compared to the other hybrid systems regarding some non-eco-friendly pollutants.

***Keywords**: Turkey, Renewable energy, Renewable energy Utilization,*

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1. INTRODUCTION

Main indigenous energy resources in Turkey are lignite, hydro and biomass. Power is essentially generated by thermal power plants burning fossil energy resources as well as geothermal energy, and hydro power plants. As of the end of 2016, 67.6% of the electricity production in Turkey was derived from the natural gas and coal fired thermal power plants, 24.6% from hydroelectric power plants and only 7.8% from renewable energy sources. It means that as stated in Table 1, although Turkey has many kinds of energy resources, Turkey is highly dependent on fossil energy sources at the point of electricity generation [1-3].

There is a shift towards renewable energy sources in humans due to reasons such as the increase in electricity demand (depending on the ever-increasing population and unavoidable technological advances), the ecological disadvantages (global warming based on emission gases) caused by the energy obtained from fossil sources, and the decrease in the cost of energy generated from renewable depending on the technological developments over time [1, 4-7]. Mankind has been aware of renewable energy for a long time and using it for many purposes. Recently, the popularity of renewable energy sources has increased considerably [1, 8].

Table 1. The situation of energy resource potentials in Turkey as of 2015

Resource	Potential
Lignite	14.8 billion tonnes
Coal	1.3 billion tonnes
Asphaltit	82 million tonnes
Crude oil	7.167 million barrels
Bitum	1.6 billion tonnes
Hydraulic	160 billion kWh/year
Natural Gas	23.2 billion m^3
Wind	48,000 MW
Geothermal	4.99 btep (2000 MW of the total potential is suitable for electricity generation)
Biomass	20 Mtep
Solar energy	1,500 kWh/m^2-year
Uranium	9,129 tonnes

In Table 2, technical wind energy potentials of European countries are given and it is especially noticed that Turkey has the first place among the European countries regarding the wind energy potential [8]. According to REPA (Turkey's wind energy potential atlas), Turkey has a wind energy potential of 48000MW. The total area for this potential corresponds to 1.3% of the total territory surface area of Turkey.

The installed capacity of licensed wind power plants by the end of 2016 is 5751.3MW. Turkey is currently exploiting only about 12% of its total wind energy potential. Furthermore, Turkey has a high solar energy potential because of its geographical position. According to Turkey's solar energy potential atlas (GEPA), the total annual sunshine duration is 2737 hours, corresponding to 7.5 hours per day, and the total annual solar energy capacity is 1527 kWh/m^2year. By the end of 2016, with the establishment of unlicensed power generation plants, the number of solar power plants is seen as 1043 and the installed power capacity of these power plants is 819.6 MW. Eventually, the total installed power capacity with two licensed solar energy power plants reached 832.5 MW [3]. According to the statistics, Turkey is the most advantageous country among European countries in terms of renewable energy potential. But, Turkey has utilized only about 9% of its total potential and it is still an energy dependent country because about 60% of the total electricity generation of Turkey is provided from large amount of imported oil and gas [3, 8].

Table 2. Technical wind energy potential of the European countries including Turkey [3, 8]

Countries	Land potential 1000 km^2	Seashore Potential km^2	Technical Potential MW	Technical Potential TWh/year
Turkey	**781**	**9,960**	**88,000**	**166**
England	244	6,840	57,000	114
Spain	505	5,120	43,000	86
France	547	5,080	42,000	85
Norway	324	4,560	38,000	76
İtaly	301	4,160	35,000	69
Greece	132	2,460	22,000	44
Ireland	70	2,680	22,000	44
Sweden	450	2,440	20,000	41
Island	103	2,080	17,000	34
Denmark	43	1,720	14,000	29
Germany	357	1,400	12,000	24
Portugal	92	880	7,000	15
Finland	337	440	4,000	7
Netherland	41	400	3,000	7
Austria	84	200	2,000	3
Belgium	31	280	2,000	5
Swiss	41	80	1,000	1

Nowadays, using renewable energy resources as a power supplier in a power generating system instead of conventional ones has been more popular. The system including more than one power supplier is called hybrid power generating system. Such systems both produce less harmful emission gases and are fairly less dependent on fossil fuels and also need no grid connection compared to conventional ones. They are very useful alternative ways for supplying electricity demand of the remote and isolated places from city center to which it is rather expensive to extend the gridline as well as some public and private buildings (libraries, residential etc.). Besides, they can be used in the system to generate all or any given portion of the electricity demand depending on location, regional renewable energy potential, green structure of hybrid system. It is the fact that they must be applied in a hybrid system with the support of auxiliary power suppliers because of their instable and discontinuous nature. Usually, diesel generators are used in the electrification of the isolated or remote consumers. As an alternative solution, hybrid power systems can be proposed for the diesel generators in the isolated places. [2, 9-11].

There are many studies in literature related to the renewable based hybrid power generation systems and their parametric analysis. Jose et al. reviewed the simulation and optimization techniques for configuration of PV generator, wind turbine and diesel generator to generate electricity [12]. Arribas et al. [13] installed a PV–wind hybrid system in Soria, Spain, in order to monitor the performance of the hybrid system throughout a year. They concluded that wind technology showed higher performance than other systems. They proposed a model that was applied to Bisheh village in Iran. The results showed that considering load curtailment costs, the power losses of the main grid, the penalties of pollutant gasses emissions and the elimination of energy subsides will tremendous impacts on the operation of microgrids [14]. Migoni et al. applied to the novel tools for realistic modeling and efficient simulation of Hybrid Renewable Energy Systems (HRES). It is concluded that these algorithms considered in this article are one order of magnitude faster than the classic solvers [15]. Chellali et al. performed a techno-economical study of a hybrid stand-alone system in Algeria having rich potential of wind and solar energies in order to determine the feasibility of such systems and they perform the optimization task with the software HOMER. The results show that the two sites have a promising potential [16].

Generally being far from the grid, the electricity need of the mountain houses has been met mostly by gasoline or diesel generators conventionally. As those generators are somehow uneconomical due to the oil prices that also change country to country, and have not an environmental friendly nature by their emissions. Therefore, in this paper, a mountain house in Sakarya-Turkey is designed considering renewable energy resources as main power suppliers instead of conventional ones. Therefore, the numerous hybrid renewable power generating systems in different configurations of wind turbine, PV panel, diesel generator and battery bank are considered. Additionally, a sensitivity analysis is also performed regarding wind speed and solar irradiation. Finally, after determination of the optimum hybrid power generating system, it is then compared to the other considered hybrid systems regarding emission gases composed of CO_2, CO, NO_x, HC and SO_x which threatens the environment.

2. ABOUT THE WIND AND SOLAR ENERGY OF SAKARYA

For the economic wind energy investment, a wind speed of 7 m/s or higher is required. According to REPA, the average wind speed in Sakarya is very low, such as 4-4,5m/s, while the capacity factor is far below 35% (minimum capacity factor for investment). Besides, the possible power capacity of the wind power plant that can be installed in Sakarya is only 2MW. When Sakarya province is examined in terms of solar energy, the total solar radiation is around 1400-1450 kWh/m2year [17-18]. On the other hand, even if solar or wind values for energy generation are low for a place, it is important to analyze those energy sources for electricity production to see if they are feasible when compared to generators with fossil fuel for remote buildings from the city grid. Electricity demand of the investigated building, solar and wind values of the location, and component configurations of the hybrid system must be determined to perform this analysis.3.

3. ELECTRICITY DEMAND OF THE MOUNTAIN HOUSE AND THE REGIONAL RENEWABLE RESOURCES

The total daily electricity demand of the mountain house, which is located in Sakarya (Adapazarı) / Turkey, is about 10 kWh while the peak load is 1.3 kW/h. Fig. 1 indicates the hourly average electricity demand of the mountain house.

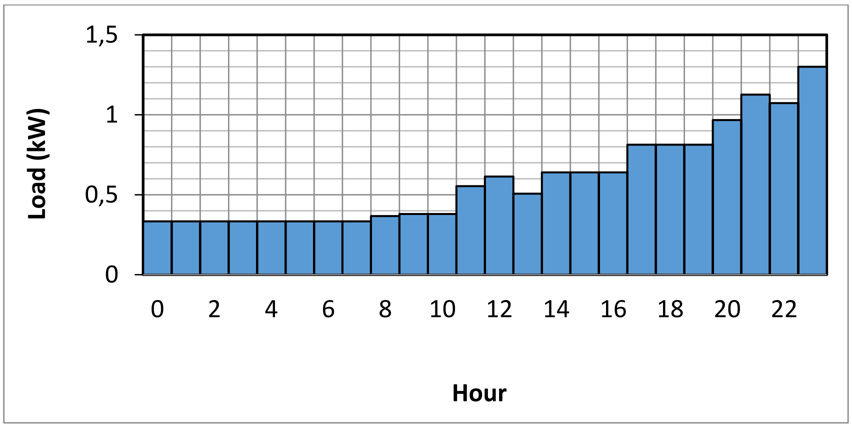

Figure 1. The hourly average electricity load demand of the mountain house

Average clearness index and average solar daily radiation of the location are 0.585 and 4.090 kWh/m2d, respectively. They were obtained using the function of “get data via internet” in the HOMER software after entering the latitude and longitude information of the location. Fig. 2 indicates the daily radiation and clearness index of the location [19, 20]. The location has the average wind speed value of 4.18 m/s. The monthly average wind speed values are indicated in Fig. 3. The *k* and *c* of Weibull parameters are about 1.73, 4.09 m/s, respectively.

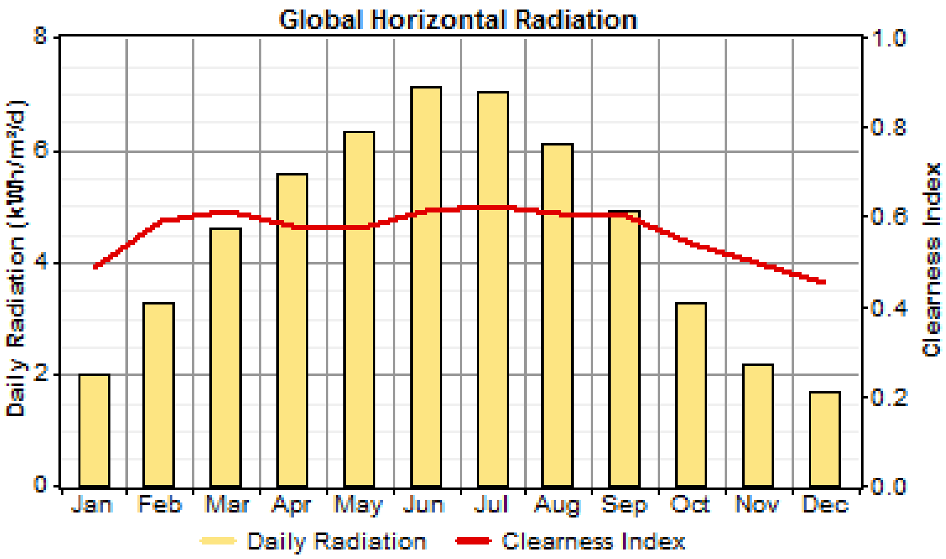

Figure 2. Daily radiation and clearness index of the location

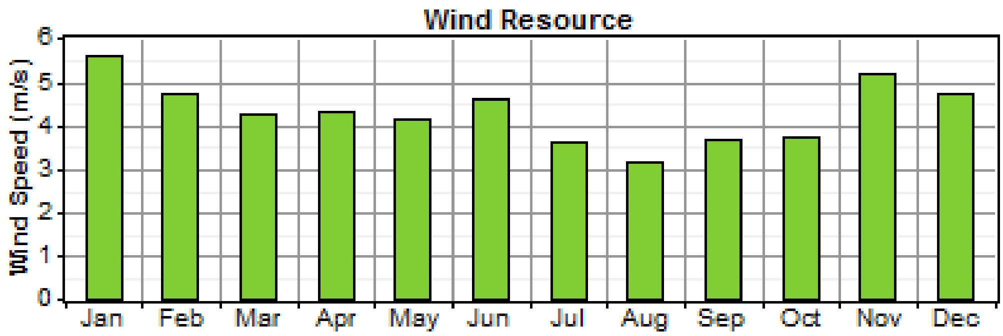

Figure 3. The monthly average wind speed values of the location

4. MAIN OPERATIONAL PRINCIPLES OF THE HYBRID SYSTEM

The designed system will consider the following main principles:

1. One diesel generator will be adequately operated to generate electricity to supply the required load if there are not sufficient solar and wind power generation in the hybrid system as well as no power supply from the battery bank.
2. If PV module and wind turbine cannot meet the demand, the battery bank will not be charged, but will be discharged to supply the demand.
3. The project lifetime is considered to be 25 years while the annual real interest rate is taken as 8% for Turkey.
4. No cost subsidy available from Turkish government is considered.

5. MAIN FEATURES OF THE HYBRID SYSTEM COMPONENTS

Hybrid power generating systems mainly comprise one or more PV panels, wind turbines, diesel generators, batteries and converters. All components of a hybrid power generating system are demonstrated in Fig. 4. Some properties of the components of the hybrid system that are composed of size/quantity, capital cost, replacement cost and operation and maintenance costs are determined according to the references [1, 21-24] and presented in detail in Table 3.

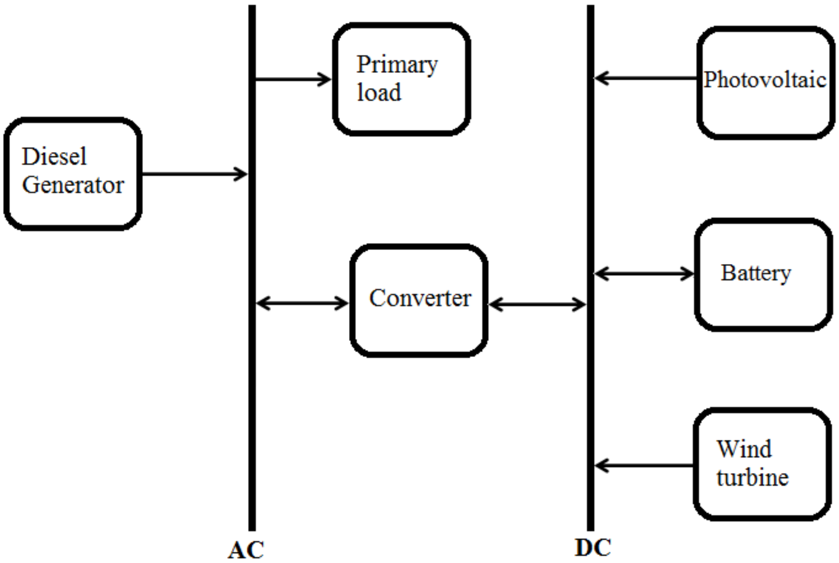

Figure 4. All components of a hybrid system

Table 3. Main components of the hybrid systems and their some expenses [19]

Component	Size (kW)/Quantity	Capital ($)	Replacement ($)	O&M ($/h/($/y)	Lifetime (y)
Diesel Generator	1	1100	900	0.040*	15
PV	1	7000	6000	0	20
Wind Turbine	1**	3900	3900	100	20
Battery	1**	220	220	4	15
Converter	1	750	750	0	15

* in the unit of $/hr, ** Pieces

Wind speeds and diesel prices are used in the sensitivity analysis of the hybrid systems because diesel prices and wind speed values stay instable and can show a fluctuating behavior in time. For this reason, changes in the variables are defined in a given ranges. According to Table 4, total number of the sensitivities is 20. Furthermore, optimization and simulation processes of the hybrid systems are run to find the optimal configuration according to the input data in Table 5. Meanwhile, some components of the designed hybrid system are chosen as follows: wind turbine is chosen as BWC XL.1 with output power capacity 1 kW while Trojan Battery Company's Trojan L16P models (6 V, 360 Ah, 2.16 kWh) are considered in the scheme [1, 21-24].

Table 4. Various wind speed and diesel prices values considered in the sensitivity analysis

Wind speeds (m/s)	Diesel prices ($/L)
3.000	0.500
3.500	1.000
4.000	1.500
4.500	2.000
5.000	

Table 5. Size/quantity of the system components considered in the processes of the simulation and optimization

PV Array (kW)	Wind Turbine (BWCXL.1) (Quantity)	Diesel Gen. (kW)	Battery (L16P) (Quantity)	Converter (kW)
0	0	0	0	0
1	1	1	12	1
2	2	2	24	2
3	3	-	36	3
4	-	-	48	-

Numerical simulations of a single stage axial fan rotor at Reynolds number of Re= 1.1 10^5 based on the rotor diameter have been performed to obtain the detailed flow field of the centrifugal fan rotor. The work has been mainly focused on the rotor configuration and the modeling of aerodynamic behavior of the blades. In addition, the rotor of the axial fan has been designed according to the requirements of the application to the cooling system of a vertical axis wind turbine. Preliminary results show a good aerodynamic behavior of the rotor at the studied conditions of velocity in the inlet of 5 m/s and rotor rotational speed of 200 rpm. However, some improvements in the airfoil design of the rotor must be done to avoid separation of the flow in the lower surface of the airfoil of the blade, when the attach angle changes from horizontal direction. At the second case, axial fan was investigated in the stagnant air condition for various angular velocities in a rotating regime. Velocity and power concepts have been studied and they are found as 0.79 m/s– 3.24 m/s, and 0.035W to 2.549 W for 300 to 1400 rpm, respectively. As a future work, more computations should be carry out at different Reynolds numbers to check the aerodynamics performance of the rotor. Also, convenient calculations should be done for the design and validations of the axial fan shroud.

6. RESULTS AND DISCUSSIONS

Main components of the designed hybrid system as well as primary load are demonstrated in Fig. 5. This figure also includes AC and DC buses through which the electricity distribution of the entire system and also energy transfer and conversion are realized.

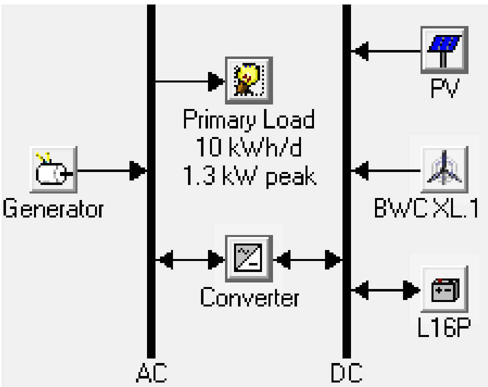

Figure 5. Hybrid power system components

After the program is operated by using the HOMER software for simulation and sensitivity analysis, some important economic and environmental results in the following tables and figures are obtained and the optimum configurations for the considered hybrid renewable energy systems are determined. In this study, various types of the power generating systems including renewable based hybrid systems as well as conventional only-diesel generator systems. The system including only a diesel generator as a power supply is considered in this study in order to compare all the hybrid systems in terms of economic and environmental factors. According to the results obtained for the conditions where the load demand is completely supplied by using only diesel generator, the followings are considered:

1. The fuel (diesel) consumption is 2398 L.
2. Operating cost is 4249 $/year and total net present cost and cost of the energy are 46,459 $, 1.195 $/kWh, respectively.
3. The operating hours of the generator is 8760 h.

Table 6 includes the emission rates of the hazardous gases that are produced by only the diesel generator.

Table 6. Current situation of the emission gases produced as a result of using only a diesel generator

Pollutant	Emissions (kg/year)
Carbon dioxide	6,077
Carbon monoxide	15
Unburned hydrocarbons	2
Particulate matter	1
Sulfur dioxide	12
Nitrogen oxides	134

Moreover, one of the important results obtained from the study is related to the optimal hybrid configuration under the available conditions (average solar irradiation value and average wind speed) of the location. Eventually it is determined that the hybrid power generation with the optimal hybrid configuration system includes a 2 kW photovoltaic array, a 1 kW wind turbine, a 1 kW diesel generator, a 1 kW power converter and 12 batteries. In addition, this system has the net present cost of 29.304 $ as well as the cost of energy (COE) as 0.752 $/kWh.

Furthermore, comparing the optimum hybrid power generating systems each other as well as the only-diesel generator in terms of emissions and COE, it is obvious that hybrid renewable power generating systems generate less harmful emission gases as well the cheapest electricity. Moreover, the optimal PV/Wind/Diesel/Battery hybrid system produces 89% less emission rates than the only-diesel generator. Added to them, PV/Wind/Battery hybrid system is a completely renewable based system, that is, it does not produce any emission, but its cost is not the most feasible one. It may be tolerated because the COE difference between two hybrid systems with different renewable fractions is too small.

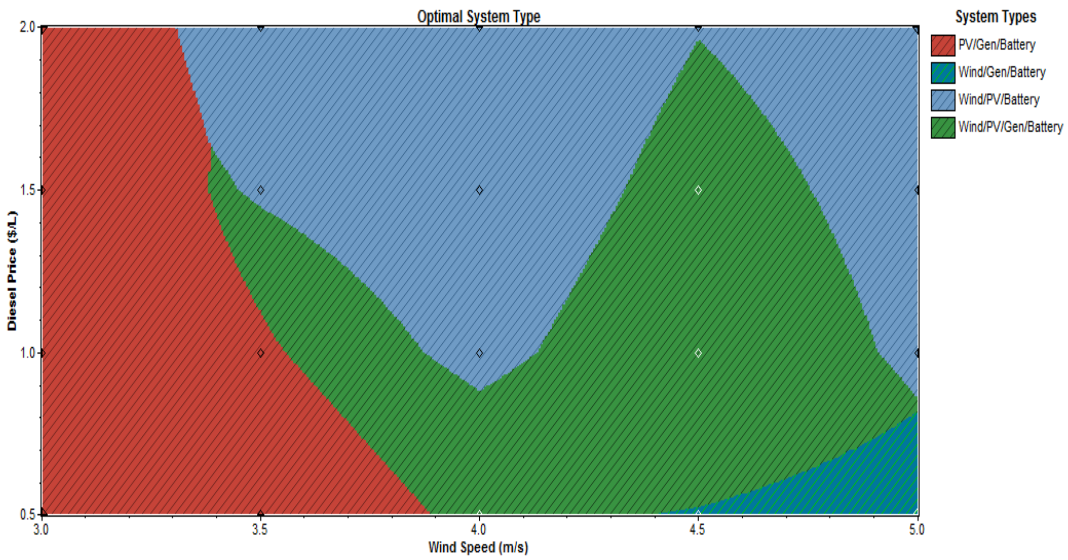

Figure 6. Optimal system types according to diesel price and wind speed

According to Fig. 6, there are four different and reasonable hybrid system types under the conditions that include numerous combinations of sensitivity variables: wind speed and diesel price. These hybrid systems are PV/Diesel/Battery, Wind/Diesel/Battery, Wind/PV/Battery and Wind/PV/Diesel/Battery. First of all, it can be concluded that at low wind speed values less than 3.4 m/s, PV/Diesel/Battery hybrid system is the most feasible for the entire diesel prices and also it is mostly appropriate under the conditions described as both diesel prices less than 1.4 $/L and also wind speeds between 3.4 m/s and 4 m/s. Secondly, there are two options while the wind speed stays above 3.9 m/s:

1. For the diesel prices less than 0.8 $/L, Wind/PV/Diesel/Battery hybrid system mostly appears the best option,
2. For the diesel prices more than 0.8 $/L, Wind/PV/Battery hybrid system is the most suitable,

3. for higher wind speed values, wind/diesel/battery hybrid system usually seems to be more appropriate, when diesel prices stay between 0.5-0.8 $/L

7. CONCLUSION

This study proposes a hybrid system configuration with renewable energy for distant places from the city grid specifically for a mountain house in Sakarya. The following remarks can be drawn from the study after examining and analyzing all the results obtained from the figures and tables which were received from the HOMER:

For the current average wind speed and solar irradiation values of the location, the hybrid power generation with the optimal hybrid configuration system includes a 1 kW photovoltaic array, a 2 kW wind turbine, a 1 kW diesel generator, a 1 kW power converter and 12 batteries. In addition, this system has the net present cost of 29.304 $ as well as the cost of energy as 0.752 $/kWh.

Using the only diesel generator as power supplier, the COE of the system is 1.195 $/kWh. Furthermore, this system produces high amount of the hazardous emission gases mentioned in Table 6. Converting the system into a complete or nearly complete renewable hybrid power generating system, the COE of the hybrid system is fairly less compared to the diesel generator system. Moreover, the new hybrid systems never produce harmful emissions or produce partially emissions according to the renewable fraction values of the system.

It is an interesting and good feature of such systems that both hybrid systems are more economic than the diesel generator systems though they are more environmental friendly. Examining the effect of the minor or major change in the sensitivity variables such as wind speed and solar irradiance value, for the numerous combinations of sensitivity variables, the most suitable hybrid systems are found to be pv/diesel/battery, wind/diesel/battery, wind/pv/battery and wind/pv/diesel/battery.

At low wind speed values, the optimal hybrid system is found to be pv/diesel/battery hybrid system. At high wind speeds, there are two options for the optimal configuration: (i) Wind/pv/battery hybrid system is the optimum one for high diesel prices; otherwise, (ii) the wind/diesel/battery hybrid system is more preferable. In the light of that work, it can be concluded that the aforementioned hybrid system configuration which mainly uses renewable energy sources can be utilized feasibly for mountain houses or similar buildings that need electricity in distant places from the city grid in Sakarya/Turkey or similar places all over the world with a close value for solar and wind.

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