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Economic analysis of a wind-battery hybrid system: an application for a house in Gebze, Turkey, with moderate wind energy potential

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Abstract

In this study, the energy demand of a house in Gebze, Turkey, is met by using wind energy as a primary energy source combined with rechargeable batteries. The wind-battery system is simulated by MATLAB while considering that energy continuity is maintained by using a sufficient number of batteries. A life-cycle cost analysis is carried out over a 20-year system lifetime because the operating time of the hybrid system is subject to the turbine life, usually assumed to be 20 years. The wind turbine generators considered are of various nominal powers, ranging from 0.6 to 450 kW. For each wind turbine, the necessary number of batteries to continuously supply the house with energy is calculated and an economic analysis of each system is performed. According to the simulation results, among the wind turbines considered in this study, Proven 2.5 (with a nominal power of 2.5 kW) appears to be the most economical turbine and produces electricity at a cost of US$0.82/kWh, while the optimum battery number for the Proven 2.5 wind turbine is 44. The total system cost obtained is $17,438.

Key Words: *Wind-battery system, wind energy, Gebze, Turkey*

1. Introduction

Energy issues and policies have mainly focused on increasing the supply of energy. Countries around the world consider the sufficient production and consumption of energy as one of their main challenges. Modern economies are dependent on energy. The provision of sufficient energy has been perceived as a central problem. Energy availability and consumption are significant in economies world-wide, so the magnitude of energy consumed per capita indicates the level of both modernization and progress in a given country. Attention has shifted

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toward a more balanced perspective, including concerns related both to demand-side and energy consumption patterns. Either way, it is fairly clear that energy is a necessary and vital tool in order to initiate the process of development and to maintain ongoing development [1-3].

In spite of the serious limitations of the earth's conventional energy resources, the demand for energy is continuously rising as a result of growing population and industrialization. At present, the utilization of fossil energy resources has increasingly disastrous effects on the global environment. In this regard, there is an urgent need to deploy sustainable and environmentally clean energy sources. An important contribution could be made by rapidly expanding the use of renewable energy sources, especially wind energy [4].

In Turkey, the attention given to wind energy by the private sector has increased considerably over the last 3 years as a result of a set of renewable energy laws that were published. For instance, while the installed capacity of wind energy in Turkey in 2004 was 20.1 MW, it reached 1074.55 MW in 2010, about 50 times greater than in 2004. In addition, projects to be supported by the government and the private sector over the next 2 years will enable the installed capacity to increase to 1545 MW [5,6]. All aspects of the installed capacity of wind energy show that there have been significant developments in Turkey's energy policy and that the former bad habit of supplying the country's energy demand through imports has been changing.

Wind is a promising energy source that can meet the energy demand of Turkey in the future. Furthermore, wind energy is clean, environmentally friendly, and exists abundantly in nature. However, there are also some disadvantages of wind, such as its discontinuity and the difficulties encountered in its storage [7].

Many regions in Turkey have been investigated in order to determine their wind energy potential and many studies have been conducted by Turkish authors. Some examples are the works of Tolun et al. [8] and Eskin et al. [9] for Gökçeada, İncecik and Erdoğmuş [10] and Şen and Şahin [11] for western Turkey, Karsli and Geçit [12] for Nurdağı in Gaziantep in southern Turkey, Durak and Şen [13] for Akhisar in Konya, Türksoy [14] and Dündar and Inan [15] for Bozcaada, Bilgili et al. [16] for Antakya and İskenderun, Genç and Gökçek [17] for Kayseri, Bilgili and Sahin [18] for the southern and southwestern regions of Turkey, Celik [19] for the southern region of Turkey, Celik [20] for İskenderun, and Ucar and Balo [21] for the coastal areas of Turkey. All of the aforementioned studies were done to determine regional wind energy potential. Additionally, there have been many studies about the cost analysis of wind energy. For example, Gökçek and Genç [22] studied the energy cost of wind energy conversion systems in central Turkey. Celik [20] analyzed economically usable power generation for various wind turbines using a model of quadratic power output function. Akdağ and Güler [23] performed wind energy cost analysis at 14 locations in Turkey and calculated the production cost of electrical energy to be between US$1.73 and $4.99/kWh for 2 different wind shear coefficients.

In this study, a system composed of a wind turbine, which is a device used to generate electricity, and a battery stack, which stores electricity in order to overcome the discontinuity problem of wind, was considered. The optimum number of batteries capable of uninterruptedly meeting the daily energy consumption of a house in Gebze (whose wind energy potential was already known) were determined under the following assumptions: only one wind turbine for all cases is employed, the battery number is not constant, and the battery number is increased to overcome the energy mismatch or disharmony between the electricity demand of the house and electricity production from the wind turbine in the hybrid system. This determination was done using a program developed in MATLAB while taking the hourly mean wind speed values of Gebze and the hourly annual energy consumption of the house into consideration.

After running programs for 6 wind turbines with different power capacities ranging from 0.6 kW to 450 kW, the optimum number of batteries in the wind-battery system was obtained. Finally, regarding the obtained optimum battery number for wind-battery hybrid systems, the cost of energy per kilowatt hour for each wind turbine was computed and the results were compared.

2. Description of the site

Gebze (ancient names: Dakibyza and Libyssa) is an industrial city in Kocaeli Province, Turkey. It is located 30 miles east of İstanbul on the northern shore of the Sea of Marmara. The largest district of Kocaeli, Gebze has experienced rapid population growth in recent years, from 159,116 in 1990 to 253,487 in 2000. Gebze accounts for 15% of Turkish industrial production [24]. Figure 1 shows the location of Gebze

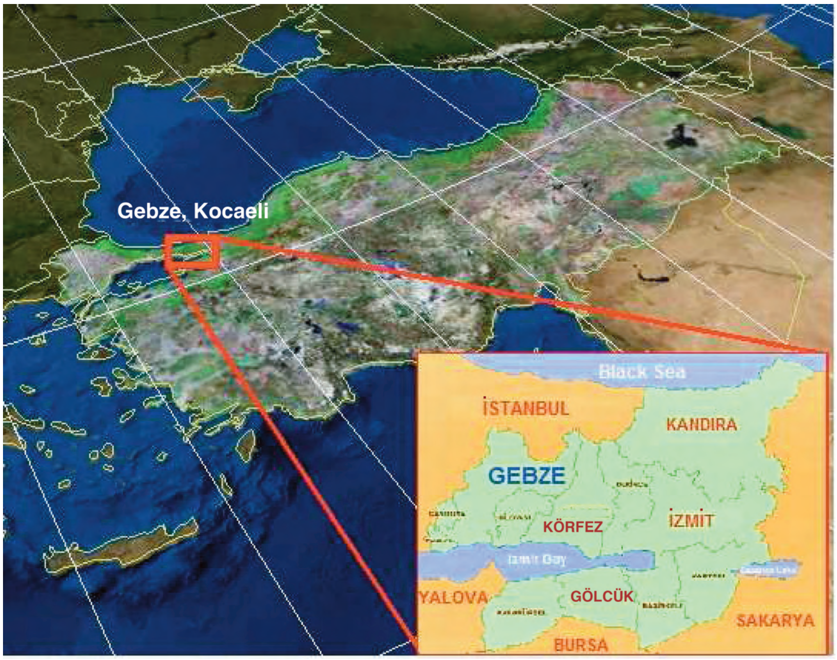

Figure 1. Gebze, Kocaeli Province: map.

3. Wind data evaluation

The hourly wind data of Gebze as observed at a height of 10 m was provided by the Turkish State Meteorological Service. Since the wind turbines used in this research were considered at 50 m above the ground, the wind velocity values measured at 10 m were extrapolated to those at 50 m. Wind velocity values measured at one altitude can be converted to a new altitude by using Eq. (1), known as the Hellmann equation [25].

$$V_w = V_{wref}\left(\frac{H}{H_{ref}}\right)^{\alpha} \tag{1}$$

V_w (m/s) is the wind speed at a height above or below the reference point, V_{wref} (m/s) is the wind speed at the reference point, H (m) is the desired height, H_{ref} (m) is the reference height, and the Hellman coefficient symbolized as α , is taken as 0.3 depending on the geographical conditions of a city with tall buildings [25,26].

Figure 2 shows the monthly mean wind speed values of Gebze. The annual mean wind speed of Gebze converted for a height of 50 m is 4.18 m/s and the annual mean power density value was calculated as approximately 220 W/m^2 by using the power density formulation expressed in Eq. (2).

$$\underline{P} = \frac{0.5\rho \sum_{i=1}^{n} (V_i)^3}{n} \tag{2}$$

Here, $\underline{P}$ (W/m^2) is the annual mean power density, ρ (kg/m^3) is the density of air and is taken as 1.225 kg/m^3, V_i (m/s) is the wind speed, and $n$is the total number of wind data.

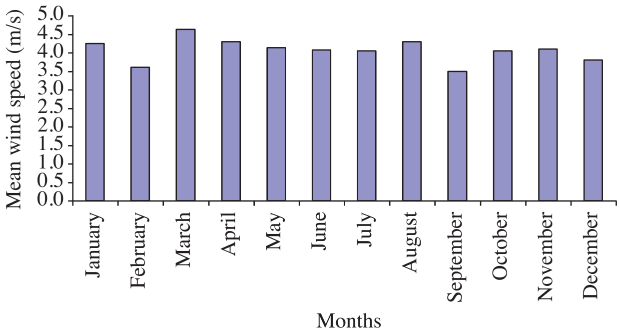

Figure 2. Monthly mean wind speed values of Gebze in 2007.

4. Load profiles of the house

In order for the energy consumption of a house to be met using wind energy, the approximate daily energy consumption of the house must be determined. It has been proven that the energy consumption of a house shows slight differences from day to day. The daily estimated energy consumption of the house in Gebze was determined considering the actual power values of household appliances as shown in Figure 3 [27,28]. As seen, the energy consumption of the house is highest between 2000 and 2200 hours, about 0.81 kW/h of peak load while it is lowest between 1400 and 1800 hours, at about 0.06 kW/h. The daily total energy consumption of the house was determined as 6.39 kW in AC. Under the assumption of constant daily energy consumption, while the annual electricity demand of the house in AC is 2334.2 kWh, it is 46,684 kWh for 20 years representing the lifetime of the wind turbine.

5. Wind-battery hybrid system

Wind-battery hybrid systems are generally widely used for rural houses that electricity has not yet reached. Its working principle is not complicated; briefly, energy is produced by a wind turbine, which is chosen based the results of cost optimization, and then it is used to fulfill the energy demand of a house. After the energy demand is met, surplus energy, expressed as the difference between the produced energy and the consumed energy, charges the batteries in the wind-battery system. In the absence of a wind source, the energy demand of the house is supplied by the batteries, which play a vital role in supplying the house with continuous and uninterrupted energy. In addition, in case of the absence of both wind energy and battery energy, a sufficient number of batteries for supplying the demand are added to the hybrid system to meet the load demand and to maintain the energy continuity.

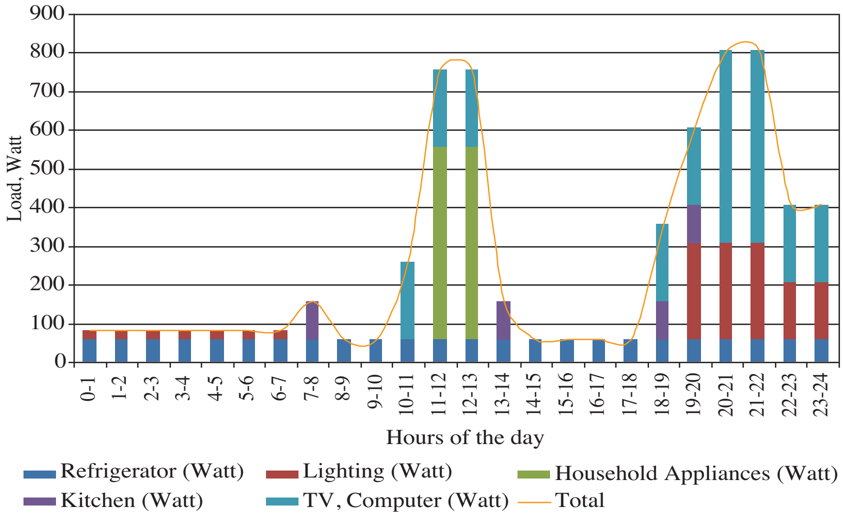

Figure 3. Hourly energy consumption of a house in Gebze [27,28].

In this study, various wind-battery systems (including wind turbines whose power capacities vary between 0.6 kW and 450 kW) were considered in order to provide continuous and uninterrupted energy for the house. Cost analysis of the energy produced in the considered systems was then performed.

A schematic representation of a wind-battery system is given in Figure 4. The components making up the wind-battery systems are basically a wind turbine, a storage unit, and a converter. A wind-battery system is designed depending on the specifications of the wind turbine with various power capacities, a storage unit, and a converter.

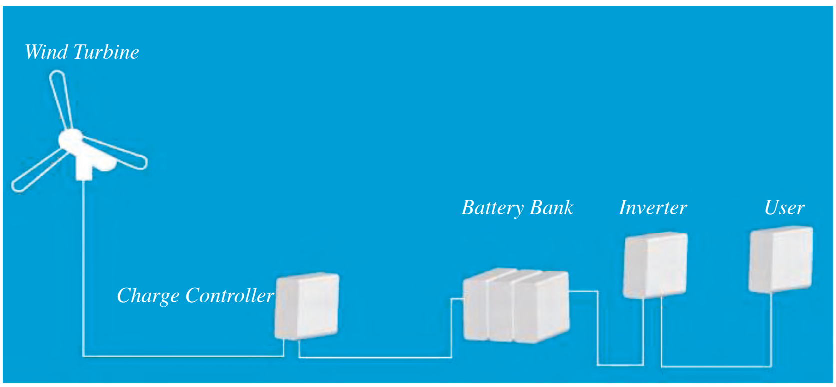

Figure 4. Schematic representation of wind-battery system.

5.1. Wind turbines

Wind turbines are devices that generate electricity by converting the kinetic energy inside wind to electrical energy. There are many kinds of wind turbines with a wide range of power capacity. In a wind-battery system, energy is supplied by wind turbines. Therefore, it is necessary to know the output power of wind turbines for variable wind speeds. Output power values of wind turbines are supplied by wind turbine manufacturers or can be calculated by applying a power estimation model, as was done in this study. Here, 6 wind turbines with different power capacities were considered. Since the house has low energy consumption, 4 small DC wind turbines, whose nominal powers varied from 0.6 kW to 15 kW, were selected. To investigate the effects of large wind turbines, 2 high-power AC wind turbines were investigated, even though we were already aware that they were inefficient in terms of the unit cost of the energy. The main specifications of the 6 wind turbines analyzed are shown in Table 1.

Table 1. The main specifications of the 6 wind turbines used in the analysis [29-31].

Wind turbines	Cut-in speed, v_c (m/s)	Cut-out speed, v_F (m/s)	Rated speed, v_R (m/s)	Rated output, P_{eR} (kW)
Proven 0.6 kW (DC)	2.50	20	12	0.6
Proven 2.5 kW (DC)	2.5	20	12	2.5
Proven 6 kW (DC)	2.5	20	12	6
Proven 15 kW (DC)	2.5	20	12	15
Micon 108 kW (AC)	3.57	26	14.75	108
Bonus 450 kW (AC)	4	26	14.75	450

From Table 1, the output power of each wind turbine can be obtained. In most cases, Eq. (3) can be applied to compute the electrical output power of a model wind turbine after determining the Weibull parameters (k and c). Calculation of the Weibull parameters is carried out in Section 6.

$$P_e = \begin{cases} 0 & (v < v_c) \\ P_e = \frac{v^k - v_c^k}{v_R^k - v_c^k} & v_c \leq v \leq v_R \\ P_{eR} & v_R \leq v \leq v_F \\ 0 & (v > v_F) \end{cases} \tag{3}$$

In Eq. (3), P_e (kW/h) is the electrical output power of the wind turbine, k is a dimensionless Weibull parameter, v (m/s) is the wind speed at any time, v_c (m/s) is the cut-in speed of the wind turbine, v_R (m/s) is the rated speed of the wind turbine, v_F (m/s) is the cut-out speed of the wind turbine, and P_{eR} (kW/h) is the rated electrical output power of the wind turbine [32].

5.2. Storage unit

The storage unit, also simply called the battery, is utilized to store energy. It is inevitable in a system intended to supply uninterrupted and continuous energy to places such as residences, hotels, or greenhouses. The storage unit used in the wind-battery hybrid system to accumulate surplus energy was a 12-V, 100-Ah lead-acid battery stack with a nominal capacity of 1.2 kWh, supplied by a Turkish company called Mutlu Akü. According to manufacturer's information, the battery's life and price are 10 years and $140, respectively [33].

5.3. Converter

A converter is required for systems in which DC components serve an AC load or vice versa. A converter can be either an inverter converting DC to AC or a rectifier converting AC to DC, or both. In the wind-battery hybrid system, a converter with a nominal capacity of 1 kWh was used due to the fact that the house has a peak load with an amount of about 0.81 kWh and the selected converter must be equal to or greater than the peak load, a well-known rule. Therefore, since the peak load is 0.81 kWh, we could assume that a 1-kW converter would meet the load for any hour that the wind turbine was serving most of the load. After some exploration to determine some characteristics of a converter with unit capacity, it was concluded that, according to sample studies of the hybrid systems on the website of the National Renewable Energy Laboratory's HOMER software, the life, price (including maintenance and replacement cost), and efficiency are 20 years, \$1800, and 90%, respectively [34].

6. Calculation of output power of wind turbines after determining the Weibull parameters

Until the Weibull parameters (k and c) in Eq. (3) are obtained, it is not possible to determine the electrical output power of a wind turbine by applying Eq. (4). Weibull parameters k and c are a dimensionless shape parameter and a scale parameter (m/s), respectively. Weibull parameters are used in the determination of the Weibull probability density function, which can give considerable information about the behavior of wind at an observation location. There are only a few methods in existence to find Weibull parameters.

In this study, the Curve Fitting Toolbox in MATLAB was used to compute parameters k and c. The Curve Fitting Toolbox, including a different form of the Weibull formulation, was applied to find the parameters ("a" and "b") considering a nonlinear least square method.

The Weibull formulation with "a" and "b" parameters is as follows:

$$f(v) = abv^{b-1} - e^{-av^b}_{,} \tag{4}$$

where a and b, the curve fitting parameters, are functions of k and c. The relation between the Weibull parameters and curve fitting parameters is expressed below.

$$k = b \tag{5}$$

$$c = e^{-\frac{\ln a}{b}} \tag{6}$$

With Eqs. (3)-(5), k and $c$are calculated as 1.4 and 4.272 m/s, respectively, based on the observed wind data for Gebze. Having obtained k and c, by applying Eq. (3) to each wind turbine, output power is calculated for various wind speed values. The electrical output power of each wind turbine for different wind speed values is tabulated in Table 2.

Annual total electricity production and average hourly electricity production of the 6 wind turbines are tabulated in Table 3. Additionally, Table 3 includes capacity factors and the longest time ranges with no electricity production for the 6 wind turbines. According to Table 3, the capacity factors of these wind turbines vary between 44% and 52%, and the longest time ranges with no electricity production are between 2 and 3 days.

7. Simulation of the proposed wind-battery hybrid system

In the Gebze study, a system with a wind turbine, storage unit, and converter was considered. The optimum number of batteries needed to meet the daily energy consumption of the house without any interruption was determined based on the following assumptions: only one wind turbine is used in the hybrid system, and the number of batteries increases to store surplus energy. Based on both the hourly mean wind speed values of

Gebze and the hourly energy consumption of the house, by using a program developed in MATLAB, for every hour:

Table 2. Electrical output power of each wind turbine for different wind speed values [29-31].

Wind speed, m/s	Proven 0.6 0.6kW, kW	Proven 2.5 2.5kW, kW	Proven 6 6kW, kW	Proven 15 15kW, kW	Micon 108 108 kW, kW	Bonus 450 450kW, kW
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0.021837	0.090989	0.218374	0.545934	0	0
4	0.069912	0.291298	0.699116	1.74779	2.964716	0
5	0.123087	0.512863	1.23087	3.077176	10.3508	31.64402
6	0.180716	0.752984	1.807162	4.517905	18.35551	65.93839
7	0.242334	1.009724	2.423337	6.058341	26.91419	102.6061
8	0.307585	1.281604	3.075848	7.689621	35.9776	141.4363
9	0.376189	1.567453	3.761887	9.404718	45.5067	182.2615
10	0.447916	1.866315	4.479157	11.19789	55.46959	224.9453
11	0.522574	2.177391	5.225739	13.06435	65.83964	269.3734
12	0.6	2.5	6	15	76.59415	315.4487
13	0.6	2.5	6	15	87.71353	363.0872
14	0.6	2.5	6	15	99.18064	412.2155
15	0.6	2.5	6	15	108	450
16	0.6	2.5	6	15	108	450
17	0.6	2.5	6	15	108	450
18	0.6	2.5	6	15	108	450
19	0.6	2.5	6	15	108	450
20	0	0	0	0	108	450
21	0	0	0	0	108	450
22	0	0	0	0	108	450
23	0	0	0	0	108	450
24	0	0	0	0	108	450
25	0	0	0	0	108	450
26	0	0	0	0	108	450

Table 3. Important production characteristics of the 6 wind turbines.

Wind turbines	0.6 kW	2.5 kW	6 kW	15 kW	108 kW	450 kW
Annual total electricity production (kW)	2712	11,301	27,121	67,804	422,157	1,720,645
Average hourly electricity production (kW)	0.31	1.29	3.1	7.74	48.19	196.42
Capacity factor (%)	52	52	52	52	45	44
Longest time range with no electricity production (days)	2	2	2	2	2.5	3

- Energy produced by the wind turbine is calculated depending on the wind speed values and power curve of the wind turbines (as a function of hourly wind speed data). Note that Table 2 shows the power curves of the 6 wind turbines.
- The produced energy is compared with the energy consumption of the house; if the produced energy is greater than the consumed energy, then the batteries are charged. Otherwise, the energy demand is supplied by batteries. If the batteries do not have sufficient energy, a new, full battery is added to the

wind-battery system so that the energy requirements of the house are continuously maintained. The additional battery then supplies the energy demand of the house.

- The optimum number of batteries that will supply uninterrupted and continuous energy to the house for 20 years, the lifetime of a wind turbine, is determined, and then, as a result of cost analysis, the unit cost of energy is calculated.

A flow diagram of the program developed in MATLAB to obtain optimal battery numbers and the unit cost of the produced energy is shown in Figure 5 in detail.

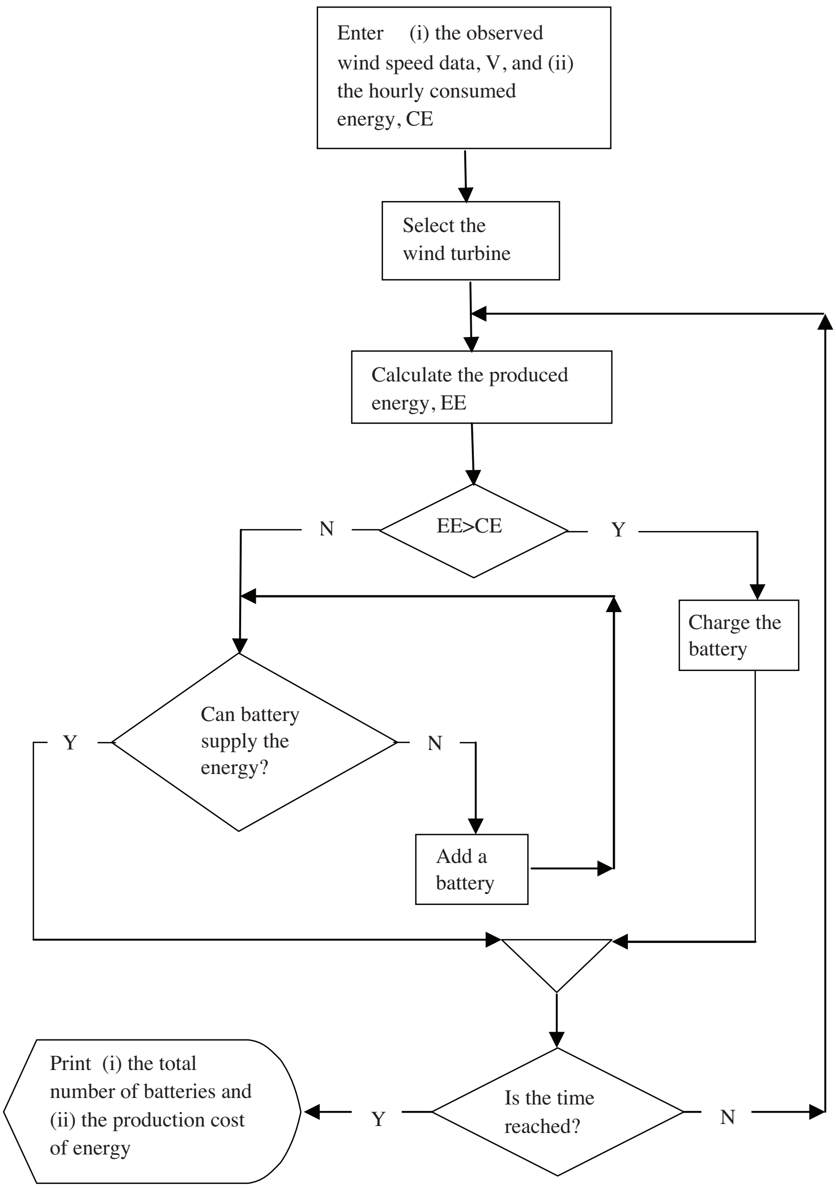

Figure 5. Flow diagram of program developed in MATLAB.

8. Calculation of optimum number of batteries and cost analysis

When the wind speed is lower than the cut-in wind speed of the wind turbine, which means that there will be no electricity production in the wind turbine because the current wind speed cannot make the blades of wind turbines rotate, and when the current batteries are completely empty, neither the wind energy generated by the wind turbines nor the current batteries can meet the energy demand. Meanwhile, when the current wind speed (the average wind speed is low, around 4.5 m/s) is slightly higher than the cut-in wind speed (which varies between 2.5 m/s and 4 m/s) of the wind turbine, there will be insufficient electricity production from the wind turbine and it will only supply a small portion of the total demand. Likewise, if the current batteries are not full enough to supply the remaining portion of the demand, both the turbine and the batteries produce energy in amounts less than the current load demand, which means that the total demand cannot be completely supplied. In such cases, an energy discontinuity in the hybrid system occurs. To overcome the energy discontinuity, meet the load demand, and maintain the energy continuity, a sufficient number of batteries capable of supplying the demand have to be added to the hybrid system.

In this study, the energy continuity of the hybrid system was maintained by adding batteries to the system. The optimum number of batteries to be used in the wind-battery system was computed. The unit cost of the energy produced by the wind-battery system was calculated when the energy demand of the house was continuously and uninterruptedly provided by the hybrid system. The program was separately run for all wind turbines and then the optimum number of batteries for the wind-battery system was calculated. The optimum battery count for each wind turbine for 20 years is given in Table 4.

Table 4. Optimum number of batteries required in the designed wind-battery systems for uninterrupted energy for 20 years.

Wind turbine type	Proven 0.6 kW	Proven 2.5 kW	Proven 6 kW	Proven 15 kW	Micon 108 kW	Bonus 450 kW
Current type	DC				AC	
Battery number*	2112	44	32	28	30	30

*for 20 years

According to Table 4, which involves the simulation findings about the number of batteries (NOB) for different wind turbines, the NOB decreases with the increasing power capacities of the wind turbine up until the wind turbine called Proven 15 kW, and then begins to increase for other wind turbines with power capacity above 15 kW. Consequently, it is concluded that a large wind turbine in the hybrid system makes the system unfeasible and uneconomical, and hence it would be better to avoid utilizing larger wind turbines in such hybrid systems established for maintaining the energy demand of any place continuously.

After obtaining the optimum number of batteries for each wind turbine, the unit price of energy generated from the hybrid wind-battery system was calculated by adding the manufacturing cost, battery cost, converter cost, installation expenses, maintenance, insurance, and capital recovery expenses, and then by dividing the annual repayment, which is calculated considering the effect of both the repayment period and the annual interest rate (in Turkey) on the total cost, by the annual total energy. Installation expenses are assumed to be 35% of the manufacturing costs of turbines. Annual maintenance price and insurance expenses for wind turbines are approximately 12.69% of the total investment, which is the sum of the manufacturing cost and the installation expenses [35].

Table 5 gives all expenses for each wind-battery system, as well as the unit price of the energy for each wind turbine. In order to calculate the cost of the electricity supply ($/kWh) of the wind-battery hybrid system, a 20-year repayment period and an interest rate of return of 9% (as published 20 November 2009 by the Central Bank of the Republic of Turkey) were taken into account.

Table 5. Cost analysis of energy for each wind turbine [35,36].

Hybrid system	With Proven 0.6	With Proven 2.5	With Proven 6	With Proven 15	With Micon 108	With Bonus 450
Turbine cost ($)	3031	6,230	11955	25,827	86,570	386,500
Installation cost ($)	1060.82	2180.63	4184.21	9039.36	30,299.50	135,275
Annual maintenance, insurance, and capital recovery expenses ($)	519.25	1067.31	2048.10	4424.54	14,830.74	66,213.25
Battery cost ($)	295,680	6160	4480	3920	4200	4200
Converter cost ($)	1800	1800	1800	1800	-	-
Total cost ($)	302,091	17,438	24,467	45,011	137,700	593,988
Annual total electricity demand (kWh)	2334.2	2334.2	2334.2	2334.2	2334.2	2334.2

For the hybrid system, including Proven 0.6, the annual repayment is initially calculated by means of Eq (7) [37]:

$$A = TC.\frac{i.(i+1)^n}{[(i+1)^n - 1]}, \tag{7}$$

where i = 9%, n = 20 years, TC (total cost) = $302,091, and A= $33,093.

The cost of supplying electricity for the combined wind/battery power station is:

$$C_c = \frac{A}{E}, \tag{8}$$

where A = $33,093, or the annual repayment; E = 2334.2 kWh, or the annual energy production of the hybrid system; and C_c = 14.18 $/kWh, the unit cost of the generated electricity.

The costs of electricity for all hybrid systems including the wind turbines are tabulated in Table 6.

Table 6. Cost of electricity for various hybrid systems.

Hybrid system	With Proven 0.6	With Proven 2.5	With Proven 6	With Proven 15	With Micon 108	With Bonus 450
Cost of electricity ($/kWh)	14.18	0.82	1.15	2.11	6.46	27.88

9. Results and discussion

It can be easily deducted from Table 6 that Proven 2.5 (with a nominal power of 2.5 kW) appears to be the most economical turbine and produced electricity at the price of $0.82/kWh. The residents of the house pay an average of $0.18/kWh (according to the electricity tariff in Table 7) to the city's electric company in Gebze. Thus, the tenants will pay almost 4 times more than the regional electric company's price if they use wind energy. In the evaluation of the energy unit price, it should be remembered that the location of the wind turbine was chosen randomly and the wind potential of this location is very low. With the same amount of consumption, a house in Çeşme, İzmir, which has almost twice the wind potential of Gebze, will have a unit energy price 8 times less than that of the house in Gebze. In that case, this system could be efficient even today [35]. Electricity tariffs for houses are shown in Table 7.

Table 7. Electricity tariffs [38].

Time	Electricity tariff ($/kWh)
0600-1700	0.18
1700-2200	0.32
2200-0600	0.097

Figure 6 gives the unit price of the electricity for each wind turbine. The electricity price per kilowatt hour decreases for the wind turbines with power capacities between 0.6 kW and 2.5 kW and increases for those with power capacities above 2.5 kW.

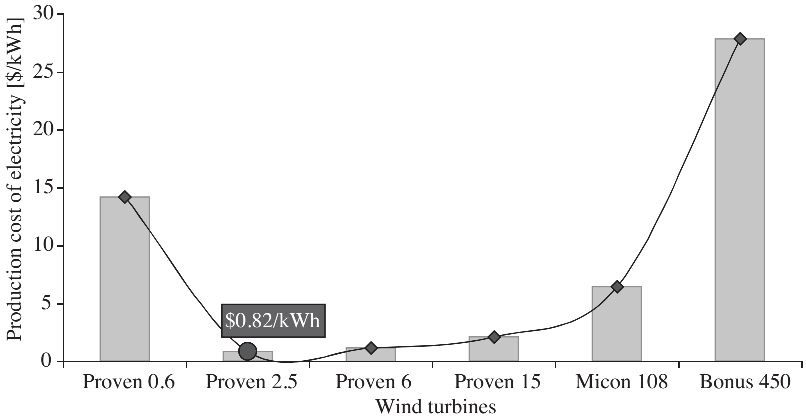

Figure 6. Unit cost of energy produced by wind turbines.

The optimum battery number of the hybrid system was obtained to overcome any energy mismatch during operation. Consequently, a hybrid system with a 2.5-kW wind turbine and a battery tank including 44 batteries (the optimum battery number for the 2.5-kW wind turbine) is more likely to supply the house with uncut energy for 20 years and maintain energy continuity.

The government in Turkey pays about $0.078/kWh for energy produced by any wind power plants. To overcome the difficulty of obtaining uncut electrical energy, the energy produced by the wind turbines could be sold directly to the government without any storage. It is evident that this trade is very economical when compared to the $0.82/kWh expense of the system. Therefore, unless fossil fuels are exhausted, the wind-battery energy system is satisfactory only for houses that have no city electricity network connection. The manufacturing of small-power wind turbines can be supported by credit and encouragement. By manufacturing them in Turkey, electricity prices per kilowatt hour can be decreased. Through technological developments, the decrease in the manufacturing cost of wind turbines will reduce the unit price of the energy.

10. Conclusion

The use of only wind power to supply a house with electricity is not possible due to the discontinuous nature of wind. The wind-battery system discussed in this paper can be used to overcome the challenges caused by inconsistent wind flow by providing a supplemental power source. The hybrid system configuration with a 2.5-kW wind turbine and a battery tank including 44 batteries (the optimum battery number for the 2.5-kW wind turbine) is more likely to supply the house with uncut energy for 20 years. However, this system was not very economical, because it was used in an area with low wind potential (Gebze, Kocaeli) and it produced electricity at the cost of \$0.82/kWh. If such a hybrid system were applied to the house to supply its electricity demand, the tenants would pay almost 4 times more than the regional electric company's price of an average \$0.18/kWh (2008). Therefore, it is recommended that the wind-battery system be used in areas with high wind potential for economic efficiency. The cost of energy generated by the hybrid system supported by a battery unit is almost 4 times more expensive compared to that of energy supplied by a grid network, because the hybrid system requires more batteries. To eliminate such a problem, other supporting alternative options, such as diesel generators, pumped hydro storage units, and fuel cells, should be integrated into such a hybrid system with battery storage units.

Nomenclature

A	Annual repayment (\$)
c	Weibull scale factor (m/s)
C_c	Unit cost of the generated electricity (\$/kWh)
E	Annual energy production of the power station (kWh)
H	Desired height (m)
H_{ref}	Reference height (m)
k	Weibull shape parameter (dimensionless)
n	Years
P_e	Electrical output power of the wind turbine (kWh)
DC	Total cost (\$)
v_c	Cut-in speed (m/s)
v_F	Cut-out speed (m/s)
V_w	Wind speed at a height above or below the reference point (m/s)
V_{wref}	Wind speed at reference point (m/s)
α	Hellman coefficient

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