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Sizing, design, and installation of an isolated wind–photovoltaic hybrid power system with battery storage for laboratory general illumination in Afyonkarahisar, Turkey

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Abstract
In this study, a battery-reinforced hybrid wind–solar power generation system of a size able to meet the electric power requirement for general illumination of the electric laboratory at Afyon Kocatepe University was dimensioned and installed. While determining the installation power of the hybrid wind–solar power generation system, the regional wind–solar energy potential and the magnitude of demanded power were the most important factors. It was decided to supply 400 W of the total 500 W of electric power required by the lamp group used for illumination of the electric laboratory from solar panels and 100 W from a wind turbine according to the wind–solar energy potential of the region and the cost analysis. For the hybrid energy-generation system that was designed and installed, by considering the data for the annual mean sunshine period and wind speed, the most suitable system components and thus the installation cost were determined. The electric power generated by the hybrid wind–solar power generation system and the electric power consumed by the laboratory illumination elements supplied with this system during one year were compared. According to the 12-month measurement results for power generation and consumption in the installed system, it was observed that the generated electric power was higher than the consumed electric power. Consequently, by not paying the total electric bill for electric power consumed by the general illumination elements, use of it for other education expenses was made possible. Besides, the installation costs in Turkey were compared with those in the countries of Denmark, Germany, Spain, and Portugal, where two important components of the dimensioned and installed hybrid wind–solar power generation system – wind and solar energy – are used effectively.

Keywords: photovoltaic, wind turbine, hybrid systems, optimization, financial analysis

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1. Introduction

Energy is the most important requirement in increasing the welfare level in the social life of humanity and the economic growth of countries. Energy sources used to meet energy needs and have changed during the historical process in parallel with technological developments. The reason for this is the steady increase in energy demand and steady decrease in fossil fuels used in energy consumption (Peidong *et al.*, 2009). Greenhouse gas emitted during consumption of fossil fuels cause serious environmental problems and this disturbs people from all strata of society. Such energy sources cause global warming in addition to air pollution, formation of acid rain, and depletion of the ozone layer (Wai *et al.*, 2008).

Because of the consumable nature of energy sources, the existence of foreign dependency and the environmental effects, and the generation of cheap and clean energy in sufficient quantities for countries has become a current problem. For this reason, the efficient use of generated energy and good use of the potential for alternative and clean renewable energy sources besides existing energy sources will be an efficient and practical option for meeting energy needs (Chen *et al.,* 2007).

Wind and solar energies are the most commonly used renewal energy sources. Increasing energy generation from renewable energy sources like wind and sun has drawn attention since the 2000s. The distribution of fossil fuel reserves around the world is not equal. However, these two energy sources can be easily obtained in many regions of the world. Turkey is a rich country in terms of renewable energy sources because of its climate zone. The electricity generation and consumption of Turkey is evaluated as belonging to the class of developing countries (Dinçer, 2011).

The installed power of the electric system in Turkey in the year 2010 was about 48 591 MW according to the data of TEDAS (Turkey Electric Distribution Joint Stock Company). Of this, 31 706 MW (65.3%) of the installed power was generated by fossil fuel thermal plants and 15 525 MW (34.7%) by hydraulic and renewable sources. While the installed power of Turkey consisting of renewable energy sources was 34 MW in 2003, it increased to 1 266 MW by 2010. According to these values, there has been a considerable increase in the amount of energy generated from renewable energy sources in Turkey (Energy Report, 2010).

In the literature, there are many studies on hybrid wind–solar power generation systems capable of storing energy. A few studies are about optimizing the renewable energy systems

(Shen, 2009; Lagorse *et al*., 2009; Ai *et al.,* 2003; Bilal *et al.,* 2010). In the hybrid wind–solar power generation system designed and realized in the campus of Frostburg State University, a 2-kW solar panel and a 1.8-kW wind turbine were used (Soysal *et al.,* 2008). By designing a micro-controller renewable energy generator and wind and solar collector in addition to the existing electric connection of a house, Fesli *et al.* (2009) generated 650 W of electric power from solar panels and 350 W of electric power from a wind turbine. Yang and colleagues suggested a method of determining the dimensions of hybrid system components, and by using this method they supplied energy to a telecommunication relay plant on the southeast coast of China (Yang *et al.,* 2009). In a study by Jinggang *et al.* (2009), a cost analysis of a wind and solar hybrid energy generation system for a villa was carried out. The period required for self-amortization of the system depending on its grid-connected and off-grid operating statuses was determined (Jinggang *et al.,* 2009). Bansal *et al.,* (2011) realized an optimization considering the safety and reliability of the system for a wind–solar energy generation system. In a study by Georges and Slaoui (2011), a wind and solar hybrid energy generation system to ensure illumination of a street in Lebanon was designed. Kusakana and Vermaak (2011) supplied a base station with a wind–solar hybrid system. Hocaoglu *et al.* (2009) found a new calculation method for dimensioning of a wind–solar hybrid system at minimum cost. Tao *et al.* (2014) determined the optimum system components for a wind–solar hybrid system and examined it in terms of economy. Damian *et al.* (2014) realized a wind–solar hybrid system modelling for a rural area.

In this study, the aim was to supply the 400 W of electric power needed by the total 500-W lamp group used for illumination of the electric laboratory from solar panels and 100 W from a wind turbine. For this purpose, the most suitable system components according to the economic installation cost were determined depending on the regional energy potential and system efficiency. With the installation of the dimensioned battery-reinforced hybrid wind–solar power system, the electric power generated by the system and electric energy consumed by laboratory illumination elements supplied by this system were compared. On the other hand, the cost analysis of hybrid power generation system components was done by conducting a comparison between the countries of Denmark, Germany, Spain, Portugal, and Turkey.

2. Components of the hybrid wind–solar energy transformation system

Hybrid energy systems can be defined as energy systems in which two or more energy sources are used together to generate electric power. In hybrid energy systems, a few electricity generation elements are brought together to meet the electric power demand of a plant, rural house, or urban house at a short or long distance from the electric grid (Elhadidy and Shaahid, 2005). The hybrid energy systems may be independent from the central electrical grid (off-grid) or grid-connected. The main purpose of hybrid energy systems is to supply the load uninterruptedly. In Figure 1, the wind–solar hybrid power generation system to be installed is shown.

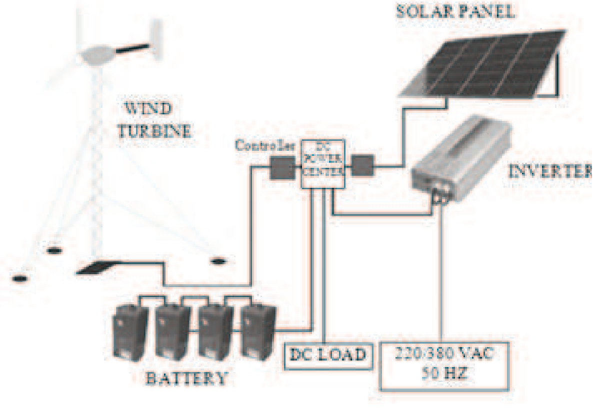


Figure 1: Wind–solar hybrid power generation system

The virtue of hybrid power generation systems over power generation systems that supply electric energy from a single source is their ability to supply electric power from another source in a reliable and continuous manner in the event that supply from one of the sources in the hybrid system is interrupted or decreases (Wang and Singh, 2006). A hybrid energy system consisting of only renewable energy sources is generally sufficient for supplying small loads. In a grid-connected hybrid energy system, electric power can be purchased from the grid and surplus electric power that may occur at definite times can be sold to the grid as well. In the case of energy surplus generated by off-grid systems, energy can be stored in batteries.

2.1 Photovoltaic systems and solar energy

Photovoltaic (PV) cells directly transform a solar beam into direct electric current with the principle of photon radiation and realize the electric power generation process as long as sufficient light exists. There are no movable parts in solar panels for the generation of electric power. The available sun beams that may be used for the generation of electricity after they reach the earth is about 1000 W/m^2 in a clear and sunny area. The power generated by solar panels used today under this radiation per 1 m^2 is about 120–150 W. A solar panel can operate for years without a decrease in its generation efficiency (Markvat and Castaner, 2006).

The biggest advantages of solar panels are their low operating costs and high reliability at the point of electricity generation. Their biggest disadvantage is their very high initial investment costs. However, it is expected that their costs will decrease in the near future when their efficiency is increased and they become more popularized in parallel with developments in technology. Solar panels are an economical option especially for supplying small- and medium-sized loads at long distances from the network. The solar panels used today are produced in three types: a mono-crystalline structure having 12–16% efficiency on average, a polycrystalline structure having 11–14% efficiency on average, and an amorphous structure having 6–8% efficiency on average. Mono-crystalline solar panels are more expensive than polycrystalline and amorphous ones as their production is difficult in terms of technique and material quality.

They fall into two categories: off-grid and grid-connected, depending on their areas of use and they are generated and sold in different powers from a few watts-peak to 500 Wp depending on need (Solar, 2011).

Figure 2 shows an annual average solar radiation () map of Afyonkarahisar province. According to the map, solar radiation in Afyonkarahisar province is sufficient for electric generation from solar energy.

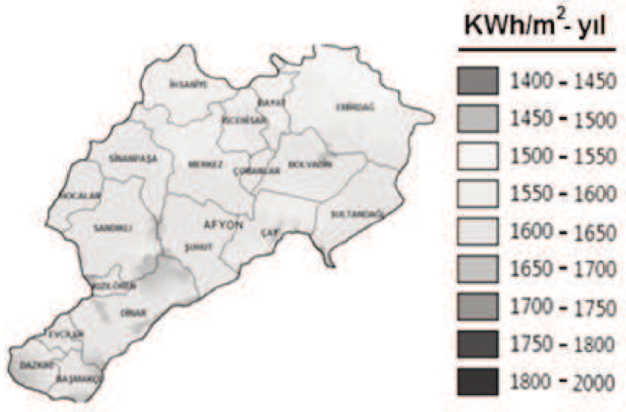


Figure 2: Sunshine radiation of Afyonkarahisar province
(EIE, 2014)

It has been observed that some small-sized entrepreneurs have carried out various studies of PV panel and system generation in Turkey reported by Aydogan *et al.,* (2010). The transformation of solar cells produced abroad into panels, accumulator chargers, and inverter systems and commercial studies related to PV illumination are the indicators that this field will develop further in time (Demirtaş, 2008).

2.2 Wind energy transformation systems

In the transformation of wind energy to electric energy, wind turbines are used. A generator connected to a wind turbine transforms mechanical energy into electric energy. The power of a wind turbine depends on variables such as the blade number, blade diameter, wind speed, output of power constant, and blade angle. The wind turbines in use can be classified according to their power, axis structure, number of blades, and area of use.

The mechanical energy obtained from the kinetic energy of wind depends on the wind speed, air density, and rotor blade diameter. The wind speed varies depending on the roughness of the surface and height. The density of air varies depending on seasonal pressure and temperature. Mechanical power generated by wind turbines is given in Equation (1) (Heier, 1998).

$$P_w = \frac{1}{2}\rho \pi R^2 V^3 C_P(\lambda, \beta) \tag{1}$$

Here, ρ is the air density, R the rotor radius, V the wind speed, C_p the power constant of the wind turbine, λ the blade speed ratio, and β the blade incline angle. The maximum mechanical power that can be obtained from wind is limited by friction. The maximum power that can be obtained according to Betz Law is 0.593 or 16/27 of the total wind power. In other words, the maximum possible value of the power constant in a wind turbine is 0.593. In practice, values of this power constant vary between 0.2 and 0.45 (Polinder et al., 2005). In Figure 3, the annual average wind speed (m/s) data of Afyonkarahisar province are given. Accordingly, a wind plant can be installed in Afyonkarahisar province.

Figure 3: Annual average wind speed (m/s) data of Afyonkarahisar province
(REPA, 2014)

The wind power changes in direct proportion to the density of the air swept out by the blades. The density of air at sea level is 1.225 kg/m^3 at a pressure of 1 atm and a temperature of 288.7ºK. Considering the elevation, temperature, and pressure of Afyonkarahisar province, the air density is calculated with Equation (2) and found to be ρ = 1.123 kg/m^3.

$$\rho = \frac{P.MW.10^{-3}}{R.T} \tag{2}$$

Here, P refers to absolute pressure (atm), MW to the molecular weight of air, R to the specific gas constant of air, and T to the absolute temperature in Kelvin (Masters, 2004).

The blade speed ratio varies depending on the wind speed, angular rotation speed of the blades (ω), and blade radius. The blade speed ratio is given in Equation (3).

$$\lambda = \frac{R.\omega}{V} \tag{3}$$

If the rotor speed is kept constant in this equation, any change in wind speed will affect the tip speed of blade. This means that the wind turbine power constant C_p and the power output generated from the wind turbine will change. However, if the rotor speed is adjusted according to the change in the wind speed, the peak speed ratio may be kept at an optimum point (Johnson *et al.,* 2006). Consequently, the maximum power output may be obtained from the system. The power that can be obtained is expressed by Equation (4) as an angular speed value.

$$\rho = \frac{P.MW.10^{-3}}{R.T} \tag{4}$$

3. Designing and dimensioning of the suggested system components

In this study, the aim is to meet a daily average requirement of 5 hours of electric power for 20 W × 25 = 500 W fluorescent lamps used in the general illumination of the electric laboratory of the Technology Faculty of Afyon Kocatepe University from the wind–solar hybrid power generation system. As the budget allocated to our department is limited, only materials needed to meet the general illumination requirement of the mentioned laboratory were supplied. Electric energy generation by PV solar panels and low-power wind turbines changes between months depending on conditions such as solar power, temperature, air density, pressure, and wind speed.

When the sunshine periods and wind speed data of the mentioned geographical region are taken into consideration, it is assumed that more benefit will be gained from solar energy than from wind energy. The cost analysis of hybrid components to be used in different scenarios to meet the energy demand shown in Table 1 was realized by using the unit prices obtained from commercial companies. According to Table 1, the lowest cost of meeting the electricity requirement of the laboratory is State I, in which only solar panels are used. However, when considering energy continuity and the importance of hybrid systems, State II was preferred. For this reason, it is desired to meet 400 W of the demanded energy with solar energy and 100 W of it with wind energy.

Table 1: The cost analysis of energy to be generated according to the system components

	PV panel	*Wind turbine*	*Cost analysis*
I	500W	–	2970 €
II	400W	100W	3175 €
III	300W	200W	3295 €
IV	200W	300W	3455 €
V	100W	400W	3520 €
VI	–	500W	3610 €

The use of hybrid wind and PV solar technologies together ensures many advantages in comparison to using them separately. Thanks to the use of the hybrid power generation system whose system

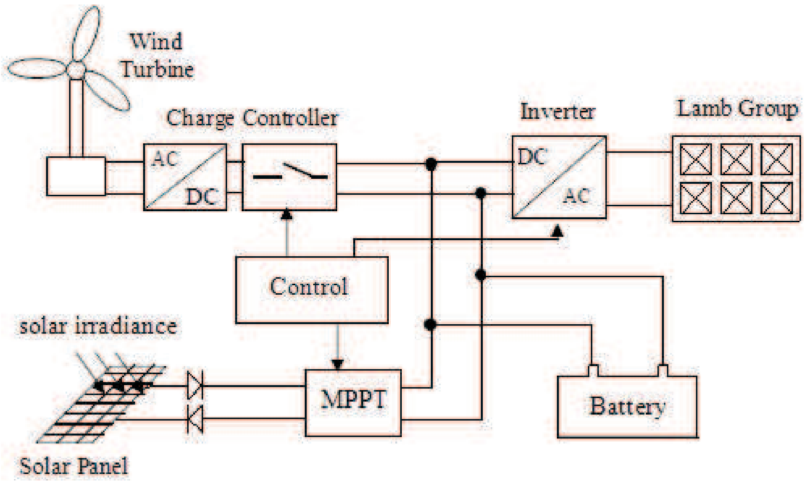


Figure 4: System connection schema

connection schema is given in Figure 4, it is possible to supply sufficient and reliable energy throughout the year.

In calculations made to determine the optimum system dimensions, studies carried out by Adejumobiand *et al* (2011) and Toklu (2002) and the geographical conditions of Afyonkarahisar province were taken into consideration. According to these calculations, suitable system elements to supply and maintain the necessary electric energy were determined. The procedures to be carried out in this section are given below in the required sequence.

1. Calculation and selection of solar panels
2. Calculation and selection of wind turbine
3. Calculation and selection of inverter power
4. Calculation and selection of charge controller
5. Calculation and selection of battery
6. Selection of conductor and fuse

3.1 Dimensioning and selection of solar panel

When the 400 W lamps in our illumination system are used for an average of 5 hours per day, the daily electric energy requirement to be met with solar panels is calculated by multiplication of the power of the lamps and period of daily use.

$$P_{PV} = P_{L1} \times t$$

$$P_{PV} = 400 \times 5 = 2000\ Wh/day \quad (5)$$

By considering the DC-DC charge controller output as 95% and the DC-AC inverter output as 90%, the requested power taking into account power efficiencies is calculated by Equation (6) (Fidan, 2010; Toklu, 2002):

$$PPC = P_{PV} \div \eta_{CHARGE} \div \eta_{INV}$$

$$PPC = 2000 \div 0.95 \div 0.9 \cong 2339\ Wh/day \quad (6)$$

If it is assumed that general losses that may occur in the system will be 10% when considering the worst situations (cable losses, attachments, development current), the total power needed per day can be expressed by the equation below (Akgün, 2006).

$$\text{PLOAD} = \text{PPC} \times 1.1 \cong 257\ Wh/day \quad (7)$$

The daily energy requirement in amperes per hour is the ratio of the total amount of energy to the system voltage.

$$P_{Ah} = P_{LOAD} \div V_{SYSTEM}$$

$$P_{Ah} = 2572 \div 12 \cong 214\ Ah/day \quad (8)$$

In Figure 5, the monthly average period of sunshine of Afyonkarahisar province is given. According to the data of State Meteorology Affairs, the average period of sunshine in the summer months is 10.56 hours and the annual average sunshine period is 6.71 hours in Afyonkarahisar province (DMI, 2011). Accordingly, the necessary PV panel current value is calculated as shown in Equation (9).

$$I_{PV} = P_{Ah} \div 6.71$$

$$I_{PV} = 214 \div 6.71 \cong 31.89\ A \quad (9)$$

According to the above calculations, the most suitable solar panel is the Conergy brand Q 80MI model. The technical specifications of the solar panel are given in Table 2. As this model consists of mono-crystal cells, it is the best option for more efficient and longer-term investments in comparison to polycrystalline and amorphous panels.

For this system, seven pieces of solar panels were connected in parallel and a value of 31.89 A was obtained.

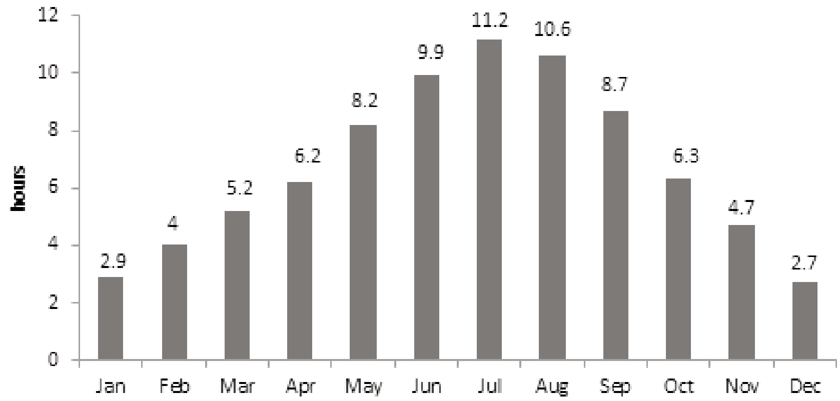


Figure 5: Annual sunshine periods of Afyonkarahisar province by month
(DMI, 2011)

Table 2: Technical specifications of solar panel
(PV, 2011)

Rated power (P_{max})	80 W
Voltage at P_{max} (V_{mp})	17.5 V
Current at P_{max}(I_{mp})	4.58 A
Open-circuit voltage (V_{oc})	21.9 V
Shurt-circuit current (I_{sc})	4.95 A

3.2 Dimensioning and selection of wind turbine

When the 100 W lamps in our illumination system are used for an average of 5 hours per day, the daily electric energy requirement to be met with wind energy is calculated by multiplication of the power of the lamps and period of daily use.

$$P_{WT} = P_{L2} \times t$$

$$P_{WT} = 100 \times 5 = 1000\ Wh/day \qquad (10)$$

The daily average energy requirement was calculated as shown in Equation (11) after power transformation output and losses were added.

$$P_{LOAD} = [P_{WT} \div \eta_{CHARGE} \div \eta_{INV}] \times 1.1$$

$$P_{LOAD} = [1000 \div 0.90 \div 0.95] \times 1.1 \cong 1286\ Wh/day \qquad (11)$$

The daily energy requirement in amperes per hour is the ratio of total amount of energy to system voltage.

$$P_{Ah} = P_{LOAD} \div V_{SYSTEM}$$

$$P_{Ah} = 1286 \div 12 \cong 107\ Ah/day \qquad (12)$$

The monthly wind speed data measured at 10 m height by the Afyonkarahisar meteorology station of the General Directorate of State Meteorology Affairs was obtained. These wind speed values were transformed from values at 10 m height to 30 m height by using the Helman equation:

$$V = V_0 \cdot \left(\frac{h}{h_0}\right)^n$$

The monthly average wind speed distribution for Afyonkarahisar province is shown in Figure 6.

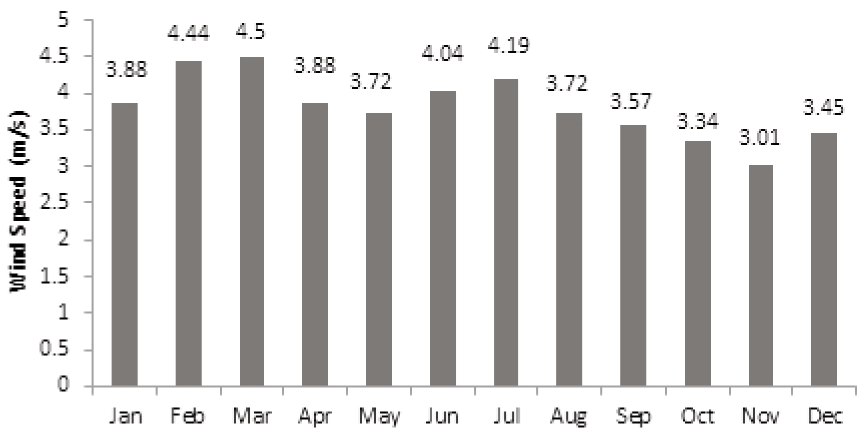


Figure 6: Wind speed distribution at 30 m height by month in Afyonkarahisar province
(DMI, 2011)

Accordingly, the annual average wind speed value was calculated as 3.84 m/s.

The R value was found by using Equation (13). This value is the turbine blade radius capable of generating the desired power (Toklu, 2002).

$$R = \sqrt{\frac{2.P}{C_p\,\rho.\pi.V^3}} \cong 0.66m \quad (13)$$

While the turbine output coefficient (C_p) is taken as 0.4 to 0.5 in calculations for two-blade high-speed turbines, it varies between 0.2 and 0.45 for low-speed wind turbines having more than two blades. Air density was calculated as $\rho = 1.123\ kg/m^3$ according to the data of State Meteorology Affairs and by using Equation (2). Maximum wind speed values in Afyonkarahisar province are given in Figure 7.

According to these values, if it is considered that wind speed rarely rises to a value of 10 m/s, the required wind turbine will have a blade diameter of 1.2 m as calculated by Equation (13) and a value of 345 W as calculated by Equation (14). Accordingly, the technical specifications of the wind turbine to be used are given in Table 3.

$$P = \frac{1}{2} \times 1{,}123 \times \pi \times 0.66^2 \times 0{,}45 \times 10^3 \cong 345\ W \quad (14)$$

Table 3: Technical specifications of wind turbine
(WT, 2011)

Rated power	400 W (12.5 m/s)
Rated Wind Turbine Voltage	12 V / 24 V, DC
Cut-in wind speed	3 m/s
Blade number	3
Rotor diameter	1.2 m
Cut-out wind speed	50 m/s

3.3 Dimensioning and selection of inverter and charge controller unit

The use of one inverter instead of using two inverters separately for DA-AA transformation of energy obtained from the wind turbine and solar panels will be more convenient in terms of both the cost and the complexity of the system. Taking into account that all the lamps in our system will be used simultaneously and the inverter output is 90%, the required inverter value is found by Equation (15).

$$P_{INV} = [P_{L1} + P_{L2}] \div \eta_{INV}$$

$$P_{INV} = [400 + 100] \div 0.9 \cong 556\ W \quad (15)$$

It was assumed that circuit elements drew excess current for a short time and that a 1000 W full sine inverter was used. The technical specifications are given in Table 4.

Table 4: Technical specifications of inverter
(SPW, 2011)

Rated input voltage	12 V DA
Output power continuous	1000 W
Output power surge	2000 W
Output waveform	Sine wave
Rated output voltage and frequency	230 V AC / 50 Hz

The controller charge current value, that is, the ratio of inverter power used for hybrid wind–solar generation system to battery voltage is given in Equation (16).

$$I_{CHARGE} + P_{INV} \div V_{BAT}$$

$$I_{CHARGE} + 556 \div 12 \cong 46.3\ A \quad (16)$$

The charge controller is the power electronic circuits that regulate the voltage on the accumulators and the load in hybrid energy generation systems. The controller keeps the accumulator continuously

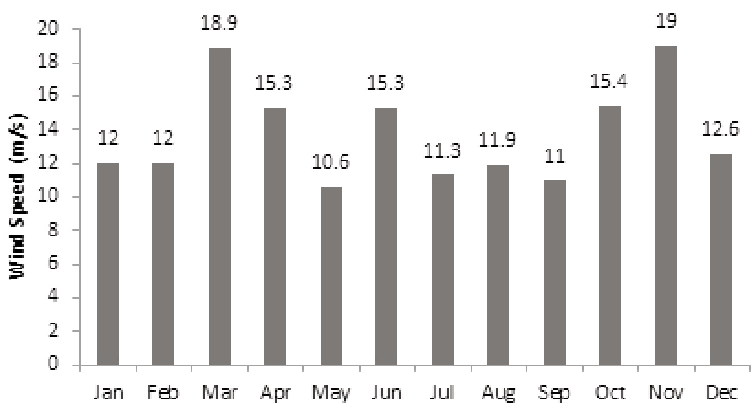


Figure 7: Monthly maximum wind speed values
(DMI, 2011)

in fully charged position without charging and discharging it excessively. In the system, an MX 60-PV MPPT Model by Outback Company, which is capable of carrying out maximum power point tracing (MPPT), was used as a charge controller. By ensuring current and tension optimization, MPPT increases the power obtained from panels by about 30% in comparison to other controllers. In PV systems whose open circuit voltage is up to 150 V, it may charge the accumulators from 12 to 60 V (Fesli *et al.,* 2009). As the life of accumulators will be extended by ensuring perfect charging for all accumulator types, thanks to the adjustable parameters, this model was used. Its technical specifications are given in Table 5.

Table 5: Technical specifications of MX 60-PV charge controller
(MPPT, 2011)

Output current rating	60 amps DC Maximum at 12, 24 or 48 V
Maximum power	12V / 800W, 24V / 1600W, 48V / 3200W
PV open-circuit voltage	150 V

3.4 Dimensioning and selection of battery

Accumulators in hybrid wind–solar generation systems were used to store the DC voltage from solar panels and wind turbines. In photovoltaic systems, accumulators mostly of lead-acid and Hi-Cd (nickel cadmium) types are used.

The aim is to store the surplus electric energy generated from the solar panels and wind turbine in accumulators. The ratio of electrical power generated by the hybrid power generation system to accumulator voltage expresses the accumulator value used in the unit of ampere-hours.

$$P_{Ah} = P_{LOAD} \div V_{BATTERY}$$

$$P_{Ah} = 3216 \div 12 = 268\ Ah/day \qquad (17)$$

Taking into account that the accumulators are discharged down to 20%,

$$K_{BAT} = P_{Ah} \times 1.2$$

$$K_{BAT} = 268 \times 1.2 \cong 322\ Ah/day \qquad (18)$$

The most convenient accumulator for the hybrid wind–solar generation system is the HZY12–100 gel-type model. The energy requirement at the desired capacity could be met by connecting three 12-V 100-Ah gel-type accumulators in parallel. Gel-type accumulators are preferred for the system as they have a deeper charging opportunity and higher charge–discharge number, their self-discharge level is lower, and they ensure a constant output current and require less maintenance compared to other accumulator types.

3.5 Selection of conductor and fuse

As much emphasis was placed on determination of the conductor cross-sections to ensure the interconnection of the system components as was placed on calculation of the other system components. As the operating voltage of system has a low value, in the determination of conductor cross-sections, the current value that will pass from the conductor and the distance between devices to be connected were taken into consideration. In the selection of system fuses, the maximum current value that will pass from the conductors became determinative. In determination of the maximum current values, 1.25 times the nominal current was taken and the fuse current values to be used in our system were determined. The conductor cross-section to be used in our system must carry this current. Accordingly, the conductor cross-sections and fuse values to be used in our system are given in Table 6.

3.6 Cost of the system

The costs of elements used in the designed hybrid power generation system were examined mainly in Turkey and in the countries of Denmark, Germany, Spain, and Portugal, in which renewable energy sources are used intensively. The average price values of brands equivalent to system components used in our cost study were found from the Internet for each country and are given in Table 7 (Ozsoy, 2011).

Sources used in electricity generation by countries in the world in 2010 were examined and the countries listed in Table 7 were selected to make a cost comparison as the share of renewable energy sources in their electric energy generation was high.

When the installation cost of the battery-reinforced hybrid wind–solar power generation system in these countries is compared to its cost in Turkey, because the ratio of renewable energy sources in electric energy generation in Turkey is low, it can be seen that the costs are high.

4. Performance of the designed battery-reinforced hybrid wind–solar power generation system

In the calculations, it has been determined that the electrical power necessary to operate the fluorescent lamp groups for 5 hours a day to give 500 W/h of general illumination of the electric laboratory is 3200 W/day when the losses are added (inverter output is 90%, charge controller output is 95%, and cable losses are 10%).

All the hybrid system components used in the design were calculated separately according to this demand. Accordingly, it was determined that seven 80-W parallel-connected mono-crystalline solar

Table 6: Conductor cross-sections and fuse values

System components	*Operating voltage (V)*	*Maximum current (A)*	*Conductor length (m)*	*Conductor section (mm^2)*	*Fuse (A)*
PV panel-controller	12	35	10	4	50
Controller-Battery	12	30	5	6	40
Wind turbine- Battery	12	35	10	10	50
Battery-Inverter	12	60	5	16	80
Inverter-consumer	220	5	15	2,5	10

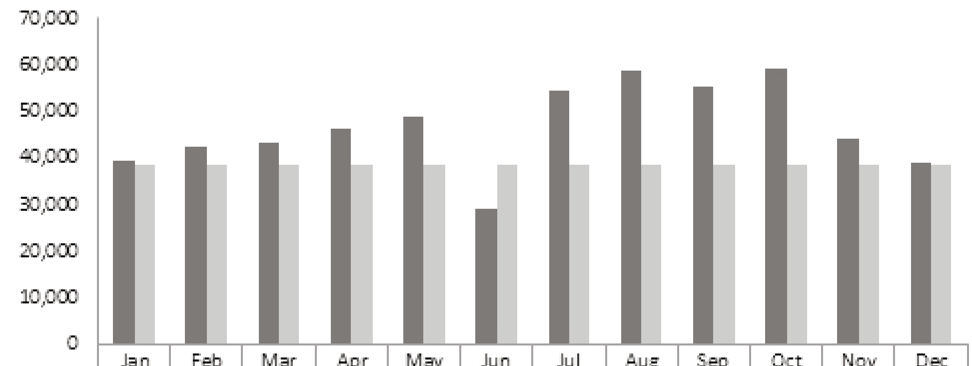
Table 7: Quantity and cost of elements used in the system

Systems components	Piece	Turkey	Germany	Spain	Denmark	Portugal
Solar panel	7	850 €	730 €	750 €	780 €	800 €
Wind turbine	1	535 €	500 €	440 €	470 €	480 €
Inverter	1	440 €	320 €	375 €	400 €	340 €
Charge Controller	1	550 €	450 €	490 €	500 €	530 €
Battery	3	800 €	500 €	800 €	770 €	590 €
Total cost		**3175** €	**2500** €	**2855** €	**2920** €	**2740** €

panels, one 400-W wind turbine consisting of a horizontal-axis and permanent magnet synchronous generator, three 12/100-Ah parallel-connected gel-type accumulator groups, one 1000 W full sine output inverter, and a charge controller whose output can be adjusted to a maximum of 60 A must be used. Then, the extent to which the electric energy generated by the installed hybrid power generation system met the electric energy consumed for general illumination of the laboratory was determined.

With installation of the designed system, the values of the electric power consumed for general illumination according to weekly course hours at the electric laboratory were recorded with the data from measurement devices in order to carry out a productivity analysis according to the power generation and consumption of the hybrid power generation system. Then, the extent to which the electric energy generated by the installed hybrid power generation system met the electric energy consumed for general illumination at the laboratory was determined. It can be seen from Figure 8 that the generation capacity of the hybrid power generation system installed as a result of calculations made for each component of the system in previous chapters easily satisfies the power consumption.

In Figure 8, data values regularly obtained from the battery-reinforced hybrid wind–solar power generation system for 12 months are expressed graphically. When the data of the energy generated by the installed hybrid power generation system and the data of the energy consumed by the lamp groups supplied by the system for 12 months since June 2011 are examined, it can be seen in Figure 8 that generation is higher than consumption in all months other than the month of June. The reason



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Generation Power (kWh)	39,348	42,449	43,172	46,353	48,737	28,841	54,477	58,563	55,409	58,941	44,137	38,943
Consumption Power (kWh)	38,592	38,592	38,592	38,592	38,592	38,592	38,592	38,592	38,592	38,592	38,592	38,592

Figure 8: Total energy generation and consumption by month

why generation is higher than consumption in June is that data could not be recorded for 15 days because a malfunction occurred in the hybrid power generation system in June 2011.

5. Conclusion

In this study, by realizing the dimensioning and installation process of a battery-reinforced hybrid wind–solar power generation system at the Ahmet Necdet Sezer campus of Afyon Kocatepe University, the components constituting the system were introduced in detail. It was observed that two parameters determined the system components constituting the designed and installed battery-reinforced hybrid wind–solar power system in the most efficient manner. These were the average sunshine period of the region and the average wind speed data. It was determined that the values of these two parameters are convenient for the efficient operation of a hybrid energy generation system installed in the city centre of Afyonkarahisar.

In the study, two important results were obtained. Firstly, while the monthly average electric energy generated by the wind–solar hybrid power generation system installed in the city centre of Afyonkarahisar was 50 kWh, the electric energy consumed per month by general illumination elements used for the purpose of illumination of the laboratory was about 38 kWh. It was observed that the hybrid power generation system more than met the electric energy demand necessary for the fluorescent lamp groups used for general illumination. Secondly, according to the energy pricing for 2014, the total cost of the annual consumption of the fluorescent lamp groups was about 180 TL. The battery-reinforced hybrid wind–solar power generation system met the requirement of the fluorescent lamp groups by generating electric energy of a value of about 237 TL during a period of one year. By using the hybrid power generation system, it became possible to spend 180 TL of the total electricity bill for consumption by general illumination elements in one year on other education expenses. Thirdly, a cost analysis of the designed and installed battery-reinforced hybrid wind–solar power generation system was realized. While the total installation cost of the hybrid power generation system was 3175 € according to market prices in Turkey for the year 2014, the cost of components used for the same system was determined to be 2500 € in Germany, 2855 € in Spain, 2920 € in Denmark, and 2740 €in Portugal.

Germany was determined as the most suitable country in terms of the cost of the system. It is hereby determined that if the installation cost of wind–solar and battery groups decreases, the effective and efficient use of alternative energy sources will increase further.

Nomenclature

P_W	power of wind turbine (Watt)
ρ	air density
R	radius of wind turbine blade (m)
V	wind speed (m/s)
Cp	power factor
P	absolute air pressure (atm)
MW	molecular weight of air (g/mol)
T	temperature (K)
P_{PV}	power to be generated by solar panels (Wh/day)
P_{L1}	power of the first armatures (Watt)
t	work time (hour)
P_{PC}	requested power taking into account power efficiencies (Wh/day)
η_{CHARGE}	efficiency of the charge controller
η_{INV}	efficiency of the inverter
P_{LOAD}	requested power taking into account general lossess (Wh/day)
V_{SYSTEM}	system voltage (Volt)
P_{Ah}	requested battery capacity of the system (Ah/day)
I_{PV}	PV panel akımı current of the pv panel (Amper)
P_{WT}	power to be generated by the wind turbine (Wh/day)
P_{L2}	power of the first armatures (Watt)
P_{INV}	inverter power (Watt)
I_{CHARGE}	current of the charge controller (Amper)
K_{BAT}	Battery capacity (Ah/day)

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