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THEORETICAL SIMULATION AND OPTIMIZATION OF THE HYBRID RENEWABLE ENERGY SYSTEMS

M.Sc. Thesis by

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We have read the thesis entitled **“THEORETICAL SIMULATION AND OPTIMIZATION OF THE HYBRID RENEWABLE ENERGY SYSTEMS”** completed by **MOHAMMED ALBABA** under the supervision of **PROF. DR. HÜSEYİN CANBOLAT** and **ASSOC. PROF. DR. DEMIRAL AKBAR** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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THEORETICAL SIMULATION AND OPTIMIZATION OF THE HYBRID RENEWABLE ENERGY SYSTEMS

ABSTRACT

The renewable energy is being the main aim for the countries all over the world. The global warming issue is getting more dangerous on our earth. The companies are aiming now to use the renewable energy to limit the harmful emissions and reduce it as much as possible.

This thesis focused on the renewable energy and its resources in Turkey. The infinite value of solar radiation and wind speed are the purpose of this study because it can produce a clean energy by using a hybrid energy system which consists of PhotoVoltaic (PV) panels and wind turbine generators, besides the use of bidirectional converter, batteries and a back-up diesel generator, in some cases, to cover the electrical load demand. The selected areas were Cubuk in Ankara and Urla in Izmir. According to the known Hybrid Optimization Model for Electrical Renewable (HOMER) program, the solar radiation and wind speed values will be taken by using the tool of NASA surface meteorology and solar energy database after entering the longitude and latitude values of the areas. The software will implement the proposed hybrid energy system, with all the possibilities and components, and will suggest the top result. The top result will be shown according to the PV panels, besides the quantity of the wind turbine generators which will being used in the hybrid energy system.

The simulation results of HOMER software suggested two hybrid energy systems for Cubuk / Ankara and Urla / Izmir. For Urla, the first hybrid system includes 800 kW PV panels, one 250 kW wind turbine generator and one diesel generator. The second hybrid system consists of 1,300 kW PV panels and three wind turbine generators of 250 kW each, without the needy of using the diesel generator, which means that the second hybrid system is producing a clean energy 100%.

Keywords: Hybrid energy systems, HOMER, simulation, solar energy, wind energy, renewable energy.

HİBRİT ENERJİ SİSTEMLERİNİN TEORİK SİMÜLASYONU VE OPTİMİZASYONU

ÖZ

Yenilenebilir enerji, dünyenın her yerindeki ülkelerin temel hedefidir. Küresel ısınma sorunu düyada her geçen gün büyüyor. Şirketler, zararlı emisyonları sınırlandırmak ve mümkün olduğunca azaltmak için yenilenebilir enerji yatırımlarına hız veriyorlar.

Bu tez Türkiye'deki yenilenebilir enerji ve yenilenebilir enerji kaynaklarına odaklanmıştır. Bu çalımada güneş ve rüzgar enerjisinin verimli kullanımını sağlayacak bir sistem tasarlanmıştır. Bazı durumlarda, elektrik şebekesine bağlı olmayan tesislerin elektrik enerjisi talebi karşılanmalıır. Bu amaçla, çift yönlü dönüştürücü, piller ve yedek dizel jeneratörlerinin yanı sıra, güneş (PV) panellerinden ve rüzgar türbini jeneratörlerinden oluşan hibrit bir enerji sistemi kullanılabilir. Araştırma için Ankara Çubuk ve İzmir Urla bölgeleri seçildi. Elektrik Yenilenebilir Hibrit Optimizasyon Modeli (HOMER) programı bölgenin boylam ve enlem değerlerini girdikten sonra NASA yüzey meteorolojisi ve güneş enerjisi veri tabanınından aldığı güneş radyasyonu ve rüzgar hızı değerlerini kullanabilmektedir. Yazılım önerilen hibrit enerji sistemini bütün imkan ve bileşenlerle birlikte simüle etmekte ve en iyi sonucu önermektedir. En iyi sonuç, hibrit enerji sisteminde kullanılacak rüzgar türbini jeneratörlerinin özellikleri yanında, PV panellerinin enerji değeri ile gösterilmektedir.

Simülasyon sonuçlarına göre, Çubuk / Ankara ve Urla / İzmir için iki hibrit enerji sistemi ele alındı. Urla için, ilk sistem 800 kW'lık PV paneller, 250 kW'lık bir rüzgar türbini ve bir dizel jeneratör içerirken, ikinci sistem, PV panelleri için 1,300 kW'lık PV paneller ile her biri 250 kW'lık üç rüzgar türbininden oluşmaktadır. İkinci sistem daha pahalı olmasına ragmen dizel jeneratör içermediğinden çevreye zararı daha azdır.

Anahtar kelimeler: Hibrit enerji sistemleri, HOMER, simülasyon, güneş enerjisi, rüzgar enerjisi, yenilenebilir enerji.

CONTENTS

NOMENCLATURE

$\mathcal{V}$	Velocity
ρ	Air density
Cp	Betz coefficient factor
AC	Alternating current
COE	Cost of energy
DC	Direct current
DOD	Depth of discharge
ETAP	Electrical transients analyser program
HAWT	Horizontal axis wind turbine
HOMER	Hybrid optimization model for electrical renewable
MPP	Maximum power point
NPC	Net present cost
NASA	National Aeronautics and Space Administration
O & M	Operation and maintenance
PV	Photovoltaic
SOC	State of charge
VAWT	Vertical axis wind turbine

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CHAPTER 1

INTRODUCTION

The usage of the hybrid renewable energy systems is increasing day after day. According to the experts all over the world, the hybrid renewable energy system is the best solution to generate a clean and an endless energy to provide it not only to the rural and isolated areas, but also to the cities. By using the renewable energy resources, the fuel emissions will be reduced noticeably and it will affect the environment in a very positive way. The hybrid renewable energy systems can be used in the micro-grid and smart grid systems which can be on-grid and off-grid systems.

On the other hand, sometimes the conventional energy sources are being used too in the hybrid renewable energy systems to make it more reliability [1].

In Turkey, the hydro, lignite and the biomass are the main domestic power sources. The power is generated usually by the hydro power plants, thermal power plants and the geothermal energy. In Turkey, the electricity produced by the gas and coal fired thermal power plants is about 67%, from the hydroelectric power plants the production is about 25% and from the renewable energy resources the energy production is about 8%. According to the Table 1.1 which shows the possibilities of the energy sources in Turkey. Table 1.1 is illustrating that in the way of generating electricity, Turkey is depending the most on the fossil energy sources.

Table 1.1 The Possibilities Of The Energy Sources In Turkey

Source	Possibility
Lignite	14.8 billion tons
Coal	1.3 billion tons
Asphaltit	82 million tons
Crude oil	7.167 million barrels
Bitum	1.6 billion tons
Hydraulic	160 billion kWh/year
Natural gas	23.2 billion m^3

Wind	150.000 GW
Geothermal	4.99 btep (2000 MW of the total possibility is suitable to generate electricity)
Biomass	20 Mtep
Solar energy	1,527 kWh/m^2-year
Uranium	9.129 tons

The world is directing to use the renewable energy resources instead of using the conventional sources to generate the electricity. There are some causes to use the renewable energy resources like the noticeable increasing in the demand of the electricity which is happening because of the increasing of the population all over the world, secondly, it is an effective way to reduce the global warming and the related results of it by cutting off the use of the fossil sources and stopping the gas emissions to the environment. One other reason which is the low price and cost of the electrical power which is produced by the renewable energy resources which makes it the best choice for the mankind in the future. The people all over the world became more aware about this kind of energy resources and where and how to use it, and lately the renewable energy resources has been increased a lot [2-6].

The possibility of the wind energy in Turkey is greater than the other countries in Europe, Turkey is the first country when taking wind energy into consideration [7]. In 2018, Turkey had installed a capacity of 7.005,1 MW through the wind power plants, now Turkey is using about 12% of the possibility of the wind energy which is about 150.000 GW according to the wind energy potential atlas in Turkey which is called REPA [8,76]. On the other hand, Turkey has a very good level for the solar radiation according to its geographical location, and as a result, the solar energy will be high. According to the solar energy potential atlas in Turkey which is called GEPA, the overall yearly capacity of the solar energy is 1,527kWh/m^2year by considering the hours each day which are seven hours and a half, and the sum of the yearly sunshine period is 2737 hours [77]. At the end of 2018 and with an increasing number of the solar energy plants, it is seen that they have a capacity of 5.062,9 MW [9,76]. As a result, Turkey has the biggest advantage in the renewable energy side by comparing it with the other European countries according to its high possibility of producing clean electricity by using the renewable energy systems, but until now Turkey has used only about 10% of its full possibilities of producing clean energy. It is depending on the oil and the gas to produce the electricity which has a big percentage which is about 60% [7,9,76].

1.1 Overview

- The renewable energy resources are exist in many shapes like solar, wind, hydroelectric and some other shapes. The hybrid system can consist of PhotoVoltaic (PV) and wind resources, PhotoVoltaic (PV) and hydrogen fuel cells resources, and many other resources and shapes [10].
- Nowadays, the hybrid PhotoVoltaic (PV) / Wind power system is one of the most common power systems in the world, it can be a very trusted system to feed the electricity to the areas which have good solar radiation and high wind speed [11].
- The simulation of the hybrid PhotoVoltaic (PV) / Wind system is a good step to make sure that the system will work properly. There are some programes which can make the simulation for the hybrid energy systems like the Hybrid Optimization Model for Electrical Renewable (HOMER) program and Electrical Transient and Analysis Program (ETAP). The simulation will take into consideration the meteorology of the selected area like the solar radiation and the wind speed values because these two factors are the most important factors in any area for such studies. The values will be taken from the NASA surface meteorology and solar energy database.

1.2 Problem Statement and Motivation of the Study

- One of the biggest problems in the world is how to produce energy in the isolated and rural areas. It's obvious that it will cost a lot to make a grid in those areas. Also, it will take time to make such a grid or even by spreading the transmission lines to those areas. The standalone solar system or wind system is not enough to supply the energy all the time without a cut-off due to the nature which is uncontrollable because the climate is changing in the four seasons. By the combining of the solar photovoltaic system and the wind system, the result will be a reliable hybrid system with enough energy to supply the electric load [11-12].

- The hybrid PhotoVoltaic (PV) / Wind energy system can generate the energy twenty four hours and supply it to the electric load using some inverters, converters and storage batteries. It is environmently friendly and has no any fuel emissions. It has the ability to expand in order to generate more energy if needed in the future. The hybrid PhotoVoltaic (PV) / Wind system is the best system as it is producing energy in the day light depending on the sun light and at night depending on the wind movement [11-12].

1.3 Objectives and Methodology

- The prime target is to draw and institute a PhotoVoltaic (PV) / Wind power system for the rural and isolated areas in Turkey and study its advantages and disadvantages. The system is consisting of PhotoVoltaic (PV) system and wind turbine generators. The simulation will be done by using the trial version of the well-known Hybrid Optimization Model for Electrical Renewable (HOMER) program and after that it will recommend the best result to apply it in reality.
- The weather data like the solar radiation and wind speed will be collected from NASA surface meteorology and solar energy database tool, which HOMER provides, depending on the latitude and longitude of the given region.
- After that, the hybrid PhotoVoltaic (PV) / Wind system will be designed according to the given and available data using HOMER program.
- Because of the varieties of the weather values for the solar radiation and wind speed, a sensitivity analysis were done to get more realistic results [11,13-14].

1.4 Outline of the Thesis

Without mentioning the introduction, the thesis has the following chapters:

Chapter 2: Contains some information about the kinds of the energy resources, the nonrenewable sources and the renewable resources. Also, it contains other information about the hybrid system and its components with some details about the photovoltaic system, wind energy and the wind turbine, the battery and the diesel generator.

Chapter 3: In this chapter, the solar radiation and wind speed values were analysed for two specific areas in Turkey, which are Ankara and Izmir.

Chapter 4: Represents the proposed load profile, the solar radiation and wind speed parameters of the selected locations and the components which were being used in the proposed hybrid PV / wind energy system while designing it.

Chapter 5: It is about the hybrid PV / wind energy system and its details and results, besides the financial evaluation and the effects on the environment.

Chapter 6: It is the last chapter which illustrates the conclusion and the suggestions.

CHAPTER 2

THE HYBRID SYSTEM AND ITS COMPONENTS

2.1 Energy Resources

There are two ways of generating electricity, first one is by using the conventional energy sources which has the name of nonrenewable energy resources and the second one is by using the renewable energy resources.

The nonrenewable energy resources such as generators which are depending on the oil, natural gas and coal that are classified under the fossil fuels. Another nonrenewable energy resource which is nuclear that is being used in the nuclear power station. The heat source in the nuclear power station is the nuclear reactor. The way of its process is like the thermal power station when the heat is being used to produce steam which is making the steam turbines working and by its connection to the generator, the electricity will be produced.

The second way of producing electricity is by using the renewable energy resources which can be divided into five sections which are the solar, wind, water (hydro), biomass and geothermal. Nowadays, the interest of using the renewable energy resources is being increased and the scientists are working hard to find the best technology of using the renewable resources to be able to get as much energy as they can by improving and developing the efficiency of those resources. Sure, in this kind of work a lot of jobs will be available for the engineers and for the workforce. Figure 2.1 illustrates the nonrenewable energy resources and the renewable energy resources and their names [15].

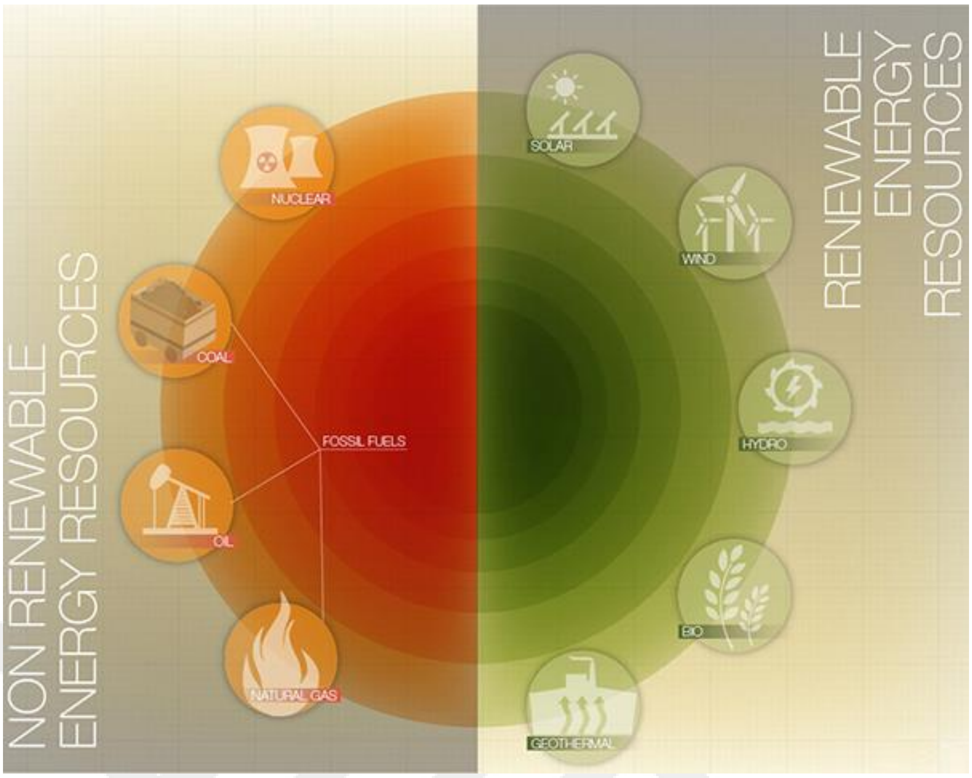


Figure 2.1 The nonrenewable and renewable energy resources

2.2 The Hybrid System

At present, a good way of producing energy by using the renewable resources is being used instead of the conventional systems of producing electricity. The energy system which contains two renewable power resources or more called a hybrid renewable energy system. This system is better than the conventional systems because it is not producing a lot of harmful emissions to the environment, the needy for the fossil fuels is much less than the conventional systems and it is not necessary to connect the system to the main grid. The most important point of using this kind of systems is that it can be used in the far areas, isolated areas, the areas which it will be expensive to extend the gridlines to it or even it can be used in the private or public buildings such as schools, libraries, houses and etc. The hybrid PhotoVoltaic (PV) / Wind energy system is the most famous system which is being used since years. This system is depending on the solar radiation and the wind speed, which can be determined in the location. On the other hand, there are some other hybrid energy systems like the hybrid wind /

hydrogen fuel cell energy system, the hybrid PhotoVoltaic (PV) / hydrogen fuel cell energy system and much more.

Because of the availability of the solar radiation and the wind movement which is changing according to the climate conditions, it is obvious that the usage of a storage battery is an important point in these types of systems. The main idea of doing that is to store the extra power which is being generated by the PhotoVoltaic (PV) modules and the wind turbines to the storage batteries and not to lose it. There is a good benefit from that which is increasing the reliability of the system to make sure it will supply the load with the enough energy all the time without a cut-off in the supplied energy.

In every system, there is a special condition, and in this system the special condition is happening when the weather turns into cloudy or not much wind movement. In that case the energy production will not be enough to supply the load. The solution in that case is to use a backup diesel generator as it is an emergency case and by doing this step, the energy will be produced and supplied to the load [16-19].

A lot of studies were made about the hybrid renewable energy systems and their results after the simulation and the analyzation. Jose et al. made a study about the techniques which being used in the simulation and optimization to configure the photovoltaic (PV), wind turbine and diesel generator to produce energy [20]. Arribas et al made a system and built it up in Soria, Spain which is a PV / Wind hybrid system to check the performance of the PV / Wind hybrid system for a year. The result was the wind is more effective than the other systems [21]. Chellali et al. made an economical study for a hybrid stand-alone system in an area which has a very good wind speed and high solar radiation in Algeria, he made the study by using HOMER software, and his results were showing that the two areas he selected have a very good possibility to build and install such this system which is a hybrid renewable energy system [22]. Marek Jaszczur also make a study in an area in Iraq called Diyala, the proposed system was a PV / wind / diesel hybrid system by using HOMER also, the results showed that the usage of the wind turbine is not workable according to the low wind speed in the selected area [23].

In the hybrid system, the sources which are being used are DC sources or AC sources.

The graph of the hybrid system is illustrated in Figure 2.2 and it shows the used components and how they are connected to the alternating current (AC) and to the direct current (DC) buses. A converter was being used which is acting as an inverter to convert the direct current (DC) to the alternating current (AC) and as a rectifier to convert from the alternating current (AC) to the direct current (DC) [1].

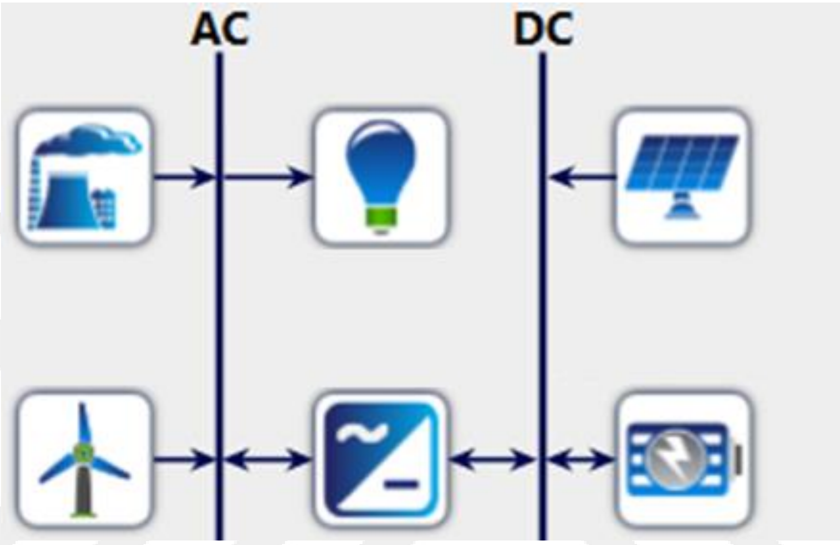


Figure 2.2 The graph of the hybrid system

The features of the Renewable Hybrid Energy System:

- Environmentally friendly as it is an effective way to reduce the release of CO2 and other harmful gases.
- It has a lower cost, the wind and solar energy are an unlimited energy resources as they are happening in nature and don't need any fuel, gas or even diesel to operate.
- There is a good point of adding two renewable energy resources or even more according to the place and its specifications.
- Doesn't need much time to combine and operate.
- Easy to find with the spreading all over the world.

2.3 Photovoltaic Solar Energy Systems

2.3.1 Overview

The sun has an unlimited energy which can be converted using some specific systems to produce enough electricity to cover the demand of the whole world in a clean and beautiful way. It has no fuel emissions and for that it is environmently friendly. In the last twenty years until now, the electrical companies are directing themselves to that kind of renewable energy as it is the best choice to keep the world a safe place to the next generations. The solar radiations which the sun is the main source of it can be converted to other forms to be useful and usable in the terms of energy resources [24].

A very famous system which produce the electrical energy from the solar radiation is known as the photovoltaic system which is using the semiconductor cells. The crystalline silicon is the main semiconductor substance which enter into the manufacture of photovoltaic cells nowadays [25].

2.3.2 The PhotoVoltaic System (PV System)

This system can produce electrical energy after the conversion of the solar radiation which is coming from the sun. It is obvious that the most important element in this system is the photovoltaic cell. A combination of those cells is called a module, and the group of the modules will produce the panels and the arrays as it is shown in Figure 2.3.

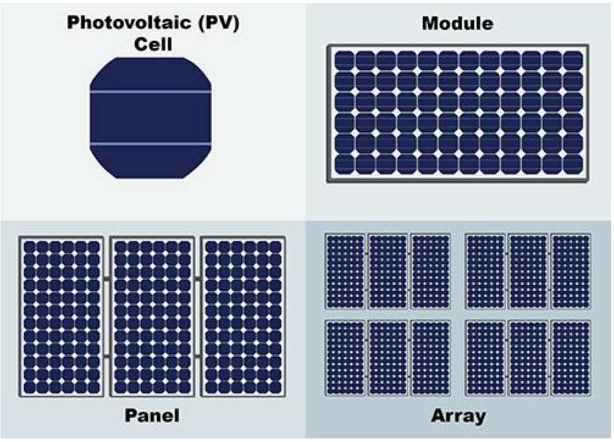


Figure 2.3 The photovoltaic cell, module, panel and array

The type of the electrical energy production from the photovoltaic cells is direct current (DC) which can be used to feed the DC loads. For the AC loads, an inverter must be used. The inverter is being used to convert the direct current (DC) to an alternative current (AC) to supply the AC loads with the electrical energy to cover its demand.

The system is normally consisting of a converter, inverter, some batteries and its charger, some devices to protect the system and the load.

There are many types of this system depending on the electricity that it is producing like the 10 kW which is small system, the medium system which is scaling between 10 and 100 kW, and the large system which produces more than 100 kW.

The main problem of the solar cells and solar modules is this, the converted electrical energy is only about 10-20% of the solar radiation which the solar cells and solar modules are taking and for that the experts are making a lot of experiences to improve that percentage to get more energy with lower costs [26].

The PV cell is the essential part of the PV system as it is converting the light into electrical energy. When the cells are gathering, they are making the module and the panel.

In the top of the PV cells, there is the glass layer, which making the solar radiation go through it and at the same time to protect the other layers in the cell from the climate changes, the dust and the other things.

The PV cell as shown in Figure 2.4 has six layers, the positive semiconductor type (P) and the negative semiconductor type (N) are from the silicon material [27].

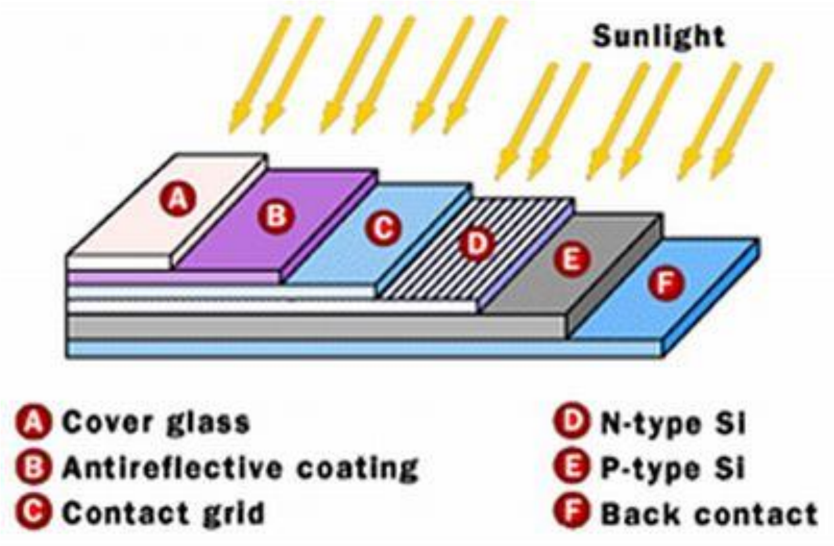


Figure 2.4 The silicon photovoltaic cell

The silicon is the most important element in the industry of the PV cells, it can be extracted from the sand and it has the chemical compound name (SiO2). By considering the essential material and its structure which is the base of making the PV cell with a various percentage of using the silicon, it is leading to specify some types of the PV cells as the following [28]:

- Monocrystalline:
  This type is the best because it is made of the pure form of silicon and for that reason, it is so expensive by comparing it with other PV cells types. Also, it has the best efficiency 15-20%. It is recognisable because of its dark black color. Figure 2.5 [29].

Figure 2.5 The monocrystalline PV cells

- Polycrystalline:

  In this type, the efficiency is lower than the monocrystalline type because of not using the pure silicon and for that it is cheaper. Its efficiency between 13-16%. It can be known by its blue color. Figure 2.6 [29].

Figure 2.6 The polycrystalline PV cells

- Thin-Film:

  It has a very low efficiency 4-12% and it needs more free areas than the other types. Figure 2.7 [30].

Figure 2.7 The thin-film PV cells

There are some other types of the PV cells and the companies are producing it by using other elements instead of the silicon.

2.3.3 The Connection Types Of The PV Modules

When the PV cells are being connected in series, the voltage will rise up and the current will stay steady. On the other hand, when the PV cells are being connected in parallel, the current will rise up and the voltage will stay stable. The same rule for the modules and the panels as shown in Figure 2.8 [24].

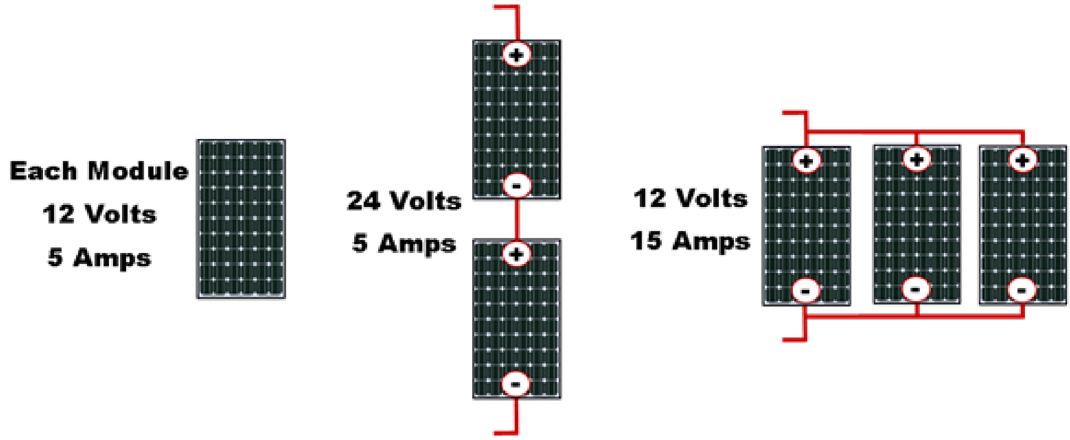


Figure 2.8 The series and parallel connection of the PV modules

The most common element which is being used in the semiconductor field to make the PV cells is the silicon as mentioned earlier, so when the sun radiation hitting the upper side of the cell, the semiconductor will soak up it. Next, the electrons will be free to move because of the light absorption. The electric fields in the PV cell will make the free electrons to flow in a particuler direction. The electrons which will flow is taking the name of current, and to make this current in-use some of the metal contacts are being used and placed in the two sides of the PV cell so it can be used to produce DC current and get the benefit from it.

By considering the voltage which is an outcome of the PV cells' built-in electric fields, and the current, the power production of the cell will be defined in watts [31].

The I-V curve and the P-V curve of a PV cell are being showed in Figure 2.9. The maximum power which is being produced in watts is depending on the maximum power point (MPP) of the voltage and the maximum power point of the current, V_{mpp} and I_{mpp} respectively.

The equation 2.1 can be used to calculate the output power of the PV cell [32],

$$P_{mpp} = I_{mpp} * V_{mpp} \tag{2.1}$$

The V_{oc} is the open voltage of the circuit and the I_{sc} is the short current of the circuit which can be found in the datasheet of the cell from the company which is producing it. It is obvious that the maximum power production will be at the maximum power point P_{mpp} and the production of the other points will be less that it [24].

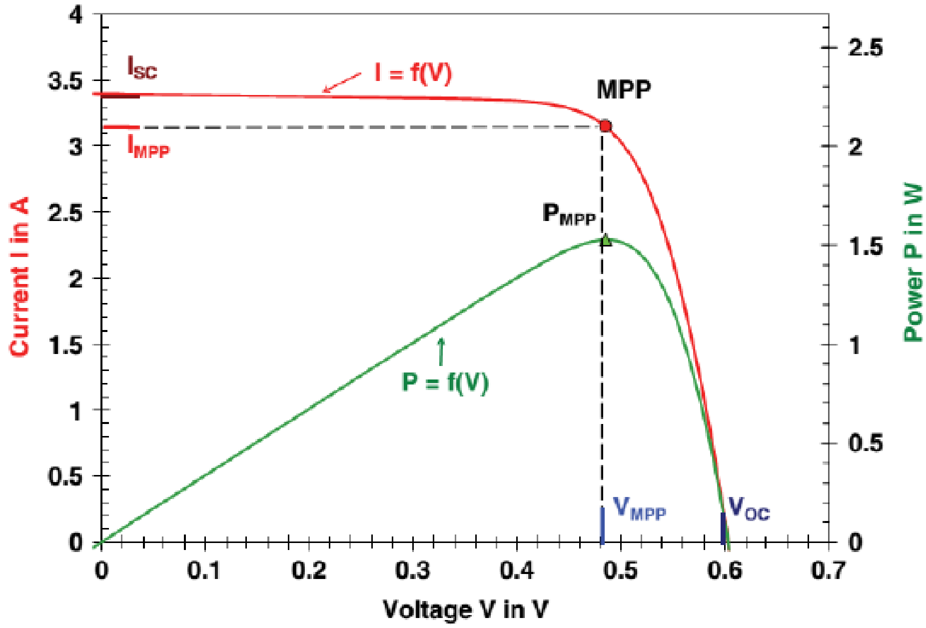


Figure 2.9 The I-V and P-V curves of a PV cell

As it is illustrated in Figure 2.10, the daily variation in insolation has some changeable values according to the climate changes. It is obvious from the Figure 2.10 that the solar radiation will start from 07:00 am in the early morning until about 05:00 pm in the evening and the maximum solar radiation will be at noon between about 12:00 and 01:00 pm , and the relationship between the solar radiation and the electrical energy which is being produced is a positive relationship.

At night, there is no any electrical energy production because of the absence of the solar radiation [33].

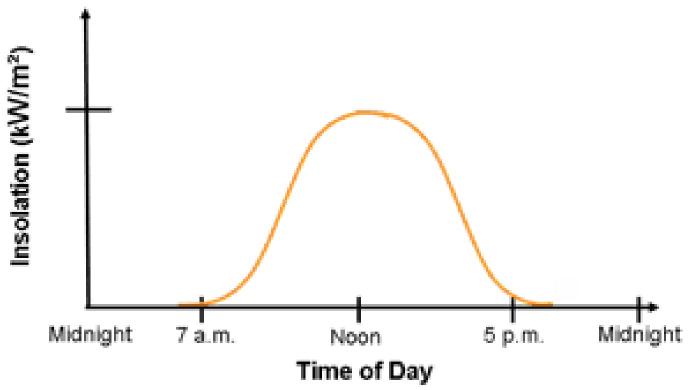


Figure 2.10 The daily variation in insolation

In general cases, and to be able to use the electricity which is being generated using the solar photovoltaic arrays which is in the direct current and invert it to an alternating current, an inverter is being used. The electrical production which is the output of the inverter is being used to feed the main load which is using the alternating current.

2.3.4 The Inverter

The device which change the current from the direct curruent (DC) to an alternating current (AC) is called Inverter. Normally, it is being connected to the direct current side in the circuit which is the side that contain the (DC) sources like the PV panels, batteries and in some cases a (DC) wind turbine which produces direct current depending on its model. The other side of the inverter is the side which the output of it will be alternating current (AC), and it will be connected to (AC) loads in direct or it will be connected to a transformer to rise the voltage up and make it better in the quality.

The inverters can be divided into two types, the first type is the central inverter and the second type is the string inverter.

The central inverter is being used in power stations. The PV panels are being connected and gathered in a combiner box which will be the output of it in the (DC) type and it will be connected to the central inverter to convert the current from direct current to alternating current. Central inverter has the advantage of the small space that it required, the cost is cheaper than the string inverters. The disadvantage of using the central inverter is that if any error happened in it, the whole system will shut down. Figure 2.11 shows the central inverter and the combiner box.

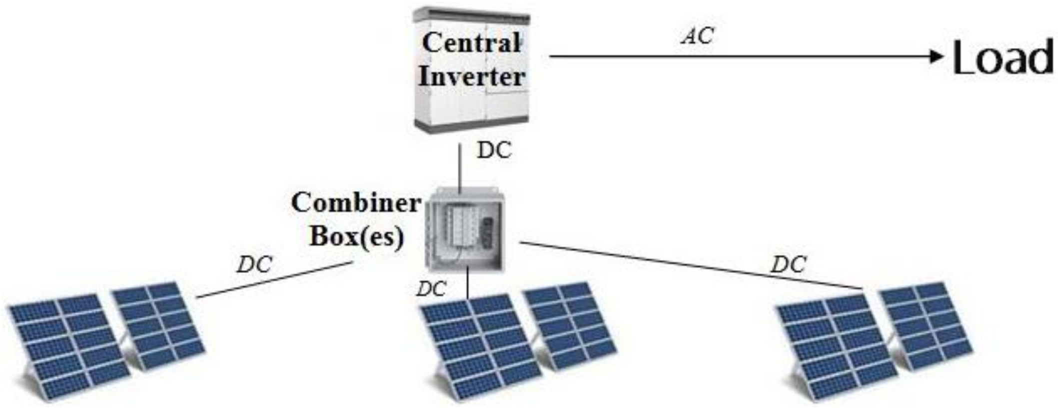


Figure 2.11 The central inverter

The string inverter as illustrated in Figure 2.12, each group of strings of the PV panels will be connected to the (DC) side of the string inverter individually. The output of the other side of the string inverter will be (AC). The advantages of using string inverter are as following, the capacity of it will be less than the central inverter, if an error happened in one string inverter the system will not shut off and it will still work without the part which the error occurred in it. The disadvantages of it are that, it will take much places to put in according to the number of string inverters which will be used and the cost will be higher than the central inverter [26,34].

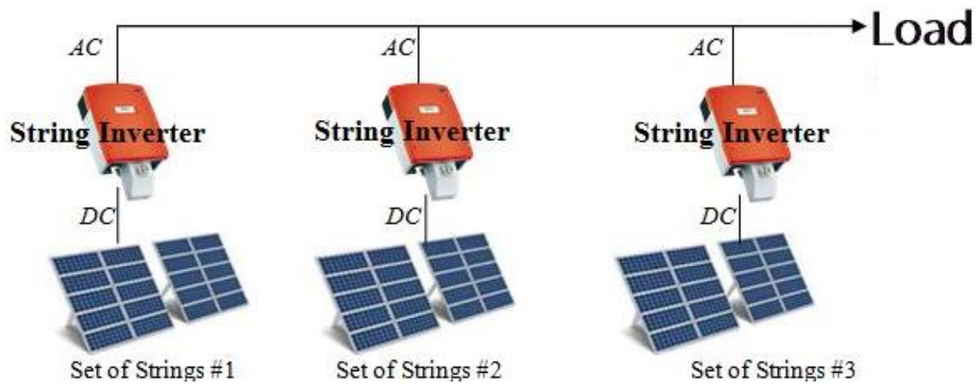


Figure 2.12 The string inverter

2.4 Wind Energy

2.4.1 Overview

Over the last twenty years, the wind energy system has got a lot of attention according to its special position of producing clean energy almost all the year. The energy is being produced by the wind turbines. The more wind speed, the more energy production. In the areas that have good wind speed, the energy production will be even more than the energy production while using the conventional methods [35].

2.4.2 Wind Turbines

The wind turbine can convert the kinetic energy from the wind into electrical energy, there are three important factors that affect in the energy produced which are the wind speed, height of the tower and the swept area of blades, the swept area is related to the rotor diameter [14].

There are two types of the wind turbines, the first one called Horizontal Axis Wind Turbine and as a shortcut is (HAWT) and the other one is Vertical Axis Wind Turbine (VAWT). Their names were chosen to be like that according to the axis which being used whether it is horizontal or vertical [36].

The Horizontal Axis Wind Turbine is the most famous type which is being used nowadays, it has two blades, three blades or even more. The common type is with the three blades.

The Vertical Axis Wind Turbine (VAWT) is different from the Horizontal Axis Wind Turbine (HAWT) in the blades side. The blades here are going from the lower side to the upper side of the turbine [36].

The HAWT type and VAWT type are illustrated in Figure 2.13 and Figure 2.14 respectively.

Figure 2.13 The Horizontal Axis Wind Turbine (HAWT)

Figure 2.14 The Vertical Axis Wind Turbine (VAWT)

On the other hand, there are two possible locations for installing the wind turbines. In that case, the name of the wind turbine will be chosen according to the location which might be onshore or offshore. If the turbine is installed onshore, it will be an onshore wind turbine.In a similar way, if the turbine is installed offshore, it will take the name of offshore wind turbine. Figure 2.15 illustrates the onshore wind turbine and Figure 2.16 shows the offshore wind turbine [37,38].

Figure 2.15 Onshore wind turbine

Figure 2.16 Offshore wind turbine

There are some positive points by using the onshore wind turbine like the following:

- It is well-know worldwide and famous among people all over the world.
- The cost of the transfer of the electricity produced is cheaper than the case of using an offshore wind turbine.
- It will be more beneficial when it will be installed near the chosen area to cover the electrical demand of it.
- In case of maintenance, of course it is cheaper in the cost by comparing it with the offshore wind turbine.

But there are some negative points on the other hand by using the onshore wind turbine like the following:

- The change of the wind speed in the onshore areas may be affect negatively on the wind turbine because it is improved to meet a specific wind speed, as a result the wind turbine will lose its efficiency in the high wind speed or low wind speed.
- In addition, the direction of the wind is changing often and this situation makes the turbine less efficiently since the turbine must face the wind direction to be affective.
- Some of the very important people are making some problems about the onshore wind turbines to stop the spreading of using it. One of their saying is the onshore wind turbine is making a noise pollution.

By taking a look at the positive points by using the offshore wind turbine, it will be like the following:

- The direction of the wind and its speed in the offshore areas are more constant than the onshore areas and as a result, the wind turbine will be more affective and it would be possible to use less offshore wind turbines to produce the same energy which being produced by using the onshore wind turbines.
- The place of the offshore wind turbine is in the sea and ocean, it will not take a place on the farms or the private lands.
- The size of the offshore wind turbine could be bigger than the onshore wind turbine and as a result the electricity produced will be more.

And by considering the negative points in the use of the offshore wind turbine, it will be like the following:

- It will cost a lot of money to transfer the electricity from the offshore wind turbine to the areas which are demanding it because will be transfered in the water.
- According to the location of the offshore wind turbine, it will be a difficult to reach it for the maintenance or in a case of happening a damage in it.
- The maintenance cost will be expensive according to the location and the way to it [37,38].

2.4.3 Fundamental Portions Of A Wind Turbine [39]

The four essential portions in a wind turbine are the foundation, the tower, the nacelle and the rotor blade as shown in Figure 2.17.

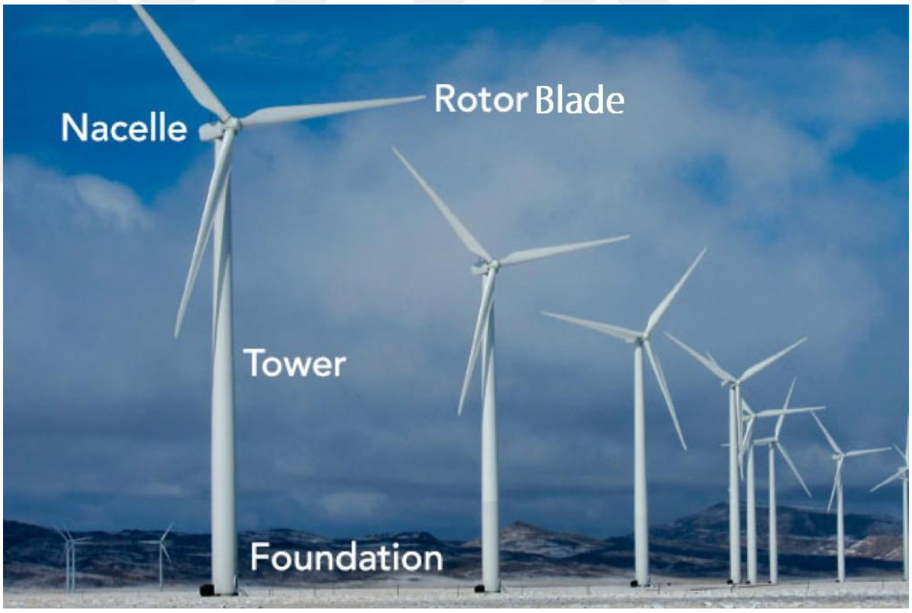


Figure 2.17 The fundamental portions of a wind turbine

From the bottom to the top, the foundation is the most important part as it is the base for the wind turbine and its equipment. The tower is responsible of connecting the base with the wind turbine and at the same time the cables are getting through it. Also, is being used from the workers to step up through it to reach the top. The nacelle is the section which contains almost all of the components like the generator, main shaft, gearbox and other components. The rotor blade is rounding because of the wind power and its speed which leads to run the generator which is located in the nacelle [1].

2.4.4 The Available Power In The Wind

- Equation 2.2 is the kinetic energy of the air currents which have mass and velocity.

$$E = \frac{1}{2} m\mathcal{V}^2 \quad \textbf{(2.2)}$$

- According to the area which is produced depending on the movement of the wind turbine blades, which have a radius (r), as illustrated in Figure 2.18 which represents the area of the circle that the blades are making while moving, the area will be calculated by using the equation 2.3.

$$A = \pi r^2 \quad \textbf{(2.3)}$$

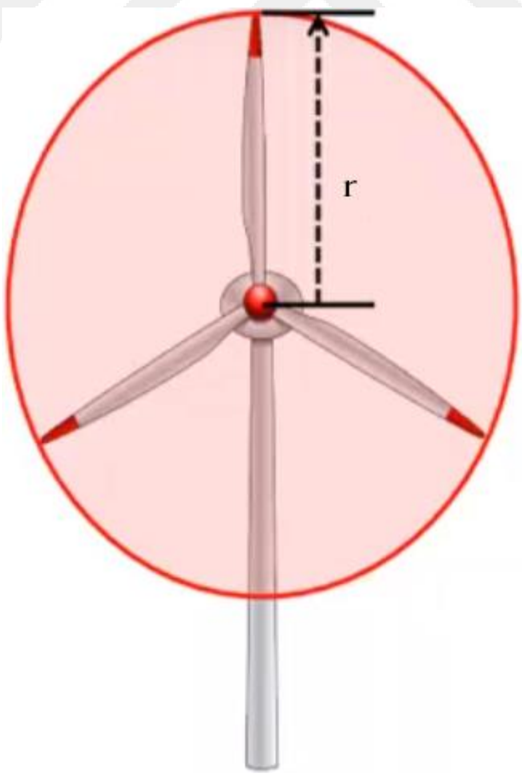


Figure 2.18 The area of the circle that the blades are making while moving

- The mass flow rate is equals to the air density multiplied with the area multiplied with the velocity of the wind as shown in the next equation 2.4.

$$m = \rho A \mathcal{V} \qquad \textbf{(2.4)}$$

- By replacing the value of the mass flow rate (3.3) in the kinetic energy equation (3.1), and by noticing that the power in the wind is equal to the kinetic energy, the new equation 2.5 will be,

$$P = \frac{1}{2} \rho A \mathcal{V}^3 \qquad \textbf{(2.5)}$$

From the last equation, it is obvious that the power is depending on the air density, the area which the blades are making and the cube of the wind speed which is the most important factor because its power of three.

- There is a factor called Betz Coefficient factor (Cp) which is affecting in the electrical energy production from the wind turbine. The wind turbine movement is a part from the wind movement and of course the wind turbine will not take the full power from the wind movement as there are some losses in the air, this factor is showing that the energy produced from the wind turbine is about 59.25% from the energy that the wind has, and the losses are about 40.75%. So, $C_p = 0.5925$.
- By multiplying the last factor to the equation, the last power equation 2.6 will be,

$$P = \frac{1}{2} C_p \rho A \mathcal{V}^3 \qquad \textbf{(2.6)}$$

- In real life, wind turbines cannot reach the Betz coefficient as it is an ideal value, on the other hand, there are some other factors which rule the turbine capacity such as the transmission lines, the generator and other parts of the wind turbine [14].

2.4.5 The Power Curve Of The Wind Turbine [40]

- To find out the relationship between the power production and the wind speed, a power curve of each wind turbine must be provided. Figure 2.19 shows an example of a power curve with its specifications according to the wind speed and the power production.

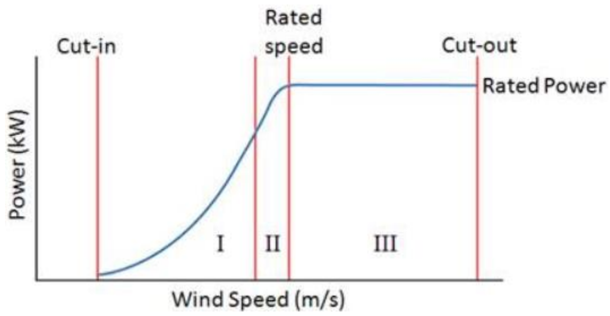


Figure 2.19 The wind turbine power curve

As it is illustrated in the previous figure, there are three areas depending on the wind speed. The first section which is making the wind turbine start moving called the (Cut-in wind speed) which has the smallest value that is capable to make the blades of the wind turbine start turning over. The power production is little in this section and it is increasing due to the increase of the wind speed.

The second section is (Rated wind speed) which has the rated output power, that means the full electricity will be generated from the turbine in that section according to the high wind speed and it will work at its extreme amplitude [41].

The last section is (Cut-out wind speed), it is obvious that the wind turbine will stop turning over in a specific wind speed and that point called the cut-out wind speed, and that is happening to protect the wind turbine and its blades from the harm which the high speed of the wind will cause to the blades and to the wind turbine [42].

2.4.6 The Relation Between The Height And The Wind Speed [12]

As illustrated in Figure 2.20, the relation between both parameters is positive.

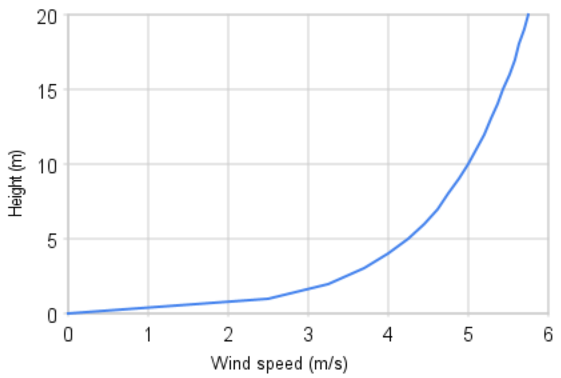


Figure 2.20 The relation between the height and the wind speed

That means the higher height, the higher wind speed. The equation 2.7 can describe this relation.

$$\frac{\mathcal{V}}{\mathcal{V}_o} = (\frac{H}{H_o})^{\alpha} \quad \textbf{(2.7)}$$

Where:

$\mathcal{V}$: is the new wind speed at the new tower height (H).

$\mathcal{V}_o$: is the old wind speed at the old tower height (H_o).

α : is the friction coefficient.

The friction coefficient is related to the terrain of the area where the wind turbine will be established, this coefficient has a various values depending on the area and its specifications. Next, the values of the friction coefficient are shown in Table 2.1.

Table 2.1 The Friction Coefficient Values

Terrain Characteristics	Friction Coefficient (α)
Smooth hard ground, calm water	0.10
Tall grass on level ground	0.15
High crops, hedges and shrubs	0.20
Wooded countryside, many trees	0.25
Small town with trees and shrubs	0.30
Large city with tall buildings	0.40

By using the wind turbine to produce the electricity, the electricity produced will be in the alternating current type. To get all of the benefits of the electrical production, a converter is being used which will convert the alternating currunt into direct current. As a result, the electrical output of the converter could be used to charge the battery with a direct current and in some cases, it could be supplied to the direct current loads.

2.4.7 The Converter

The converter is the name of the device which has the ability to work in two directions, the first direction by converting the direct current (DC) to the alternating current (AC) and in this case the converter will work as an inverter. The second direction will be when it will convert the alternating current (AC) to the direct current (DC) and in this case it will be called as a rectifier [14]. As a result, the converter can be named also a bidirectional converter [12].

The bideirectional converter is being used in the hybrid system as an important portion according to its ability by working as an inverter and a rectifier at the same time. It is able to convert the energy produced by the PV panels and the energy which is stored in the batteries which both are connedcted to the (DC) bus to alternating current and supplying the electrical load. In this case it will work as an inverter.

Also, it will work as a rectifier when it will convert the energy which is produced by the wind turbines and the diesel generator that both are connected to the (AC) bus to direct current to charge the batteries [12].

The main connections of the converter are illustrated in Figure 2.21.

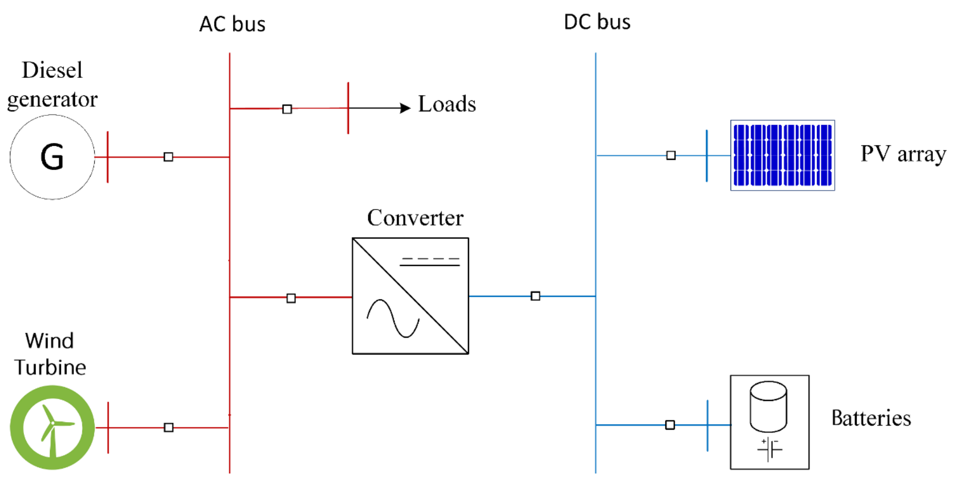


Figure 2.21 The converter and its connections

2.5 The Battery

It is obvious that the electrical energy produced by the wind turbine and the PV panels is not a constant value and it is changing according to the climate conditions becauase in some days the sun will not be availabe especially in the cloudy days, also the wind may not be available in other days. The result will be in that case is this, the produced energy will not cover the demand for the load and in this situation the solution is by using a battery bank or a group of batteries which will be connected together to be able to meet the electrical demand of the load. The produced energy from the PV panels and the wind turbines will feed the load and the excess energy produced will charge the batteries and it will be stored in it until the need of that energy to be used in case of the absence of the wind or the solar radiation. The battery will be used in the rainy days, at night or even in the low energy production. The battery will be connected to the DC bus in the hybrid system as it is a direct current source [1,24].

There are some kinds of the rechargable batteries like the nickel-based, sodium-based, lithium-ion (LI), advanced lead-acid (LA) and zinc bromine (ZnBr) flow batteries which can be used in the hybrid renewable energy systems. The first two kinds of the batteris which are the nickel-based and the sodium-based batteries are not recommended for being used because the sodium-based batteries are using nontoxic materials and they have high energy density and for that reason they will need a bigger system to make sure that the system will work in the high temperature. For the nickel-based batteries, it is known that the nickel is already a toxic material which will lead after the decomposition of it to some dangers for the environment, also, if it will be charged always in a repeated way, the maximum capacity will decrease in a fast way. After the seperation of those two kinds of batteries, it will still the lithium-ion (LI), advanced lead-acid (LA) and zinc bromine (ZnBr) flow batteries. As shown in Table 2.2, some factors were being compared for the remained batteries which were mentioned above according to some different sources [43].

Table 2.2 The comparison of some factors for some batteries

Factors	Lithium ion [44-46]	Lead acid [47-51]	Zinc bromine flow battery [52-55]
Unit cell voltage (V)	3.7	2	1.8
Power density (W/L)	1500 – 10,000	10 – 400	< 25
Energy density (Wh/L)	200	50	35
Cycle life (Cycles)	1000-5000	500 – 2000	> 10,000

Calendar life (Years)	5-20	5 – 15	10 – 15
DOD (%)	80-90	70 – 80	100
Round trip efficiency (%)	92	85	75

Figure 2.22 is showing the relation between the power density (W/L) and the energy density (Wh/L) for the three types of the mentioned batteries above in the table [43].

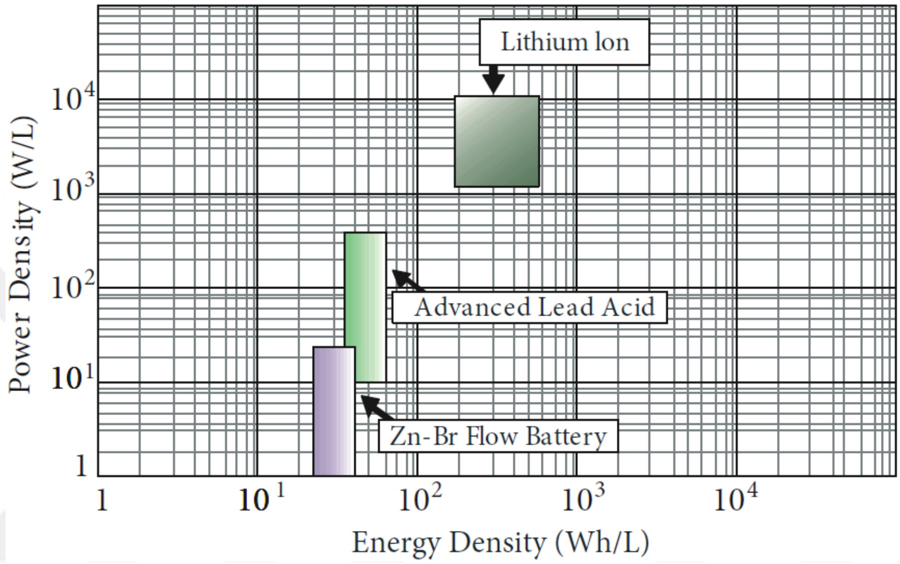


Figure 2.22 The relation between the power density and energy density for the batteries

For the hybrid PV-Wind systems, the lead-acid batteries are the most popular which are being used because of the low price, appropriation and it can be found easily almost everywhere [56].

There are some important factors related to the batteries like its capacity and power, depth of discharge (DOD), round trip efficiency and battery life.

2.5.1 Capacity And Power

The battery capacity is one of the most significant factors of the battery as it is the value that the battery will be charged to it. The capacity of the battery is measured in Ampere-Hour (Ah) which is expressing that the value is equal to the result of multiplying the current which is being used by the requested time in hours to discharge the battery [57].

In other words, the capacity is the quantity of the electricity which will be stored in the battery and it is being measured in the kilowatt hours (kWh). The power of the battery is defining the electricity that the battery is able to give and it is measured in (kW). So, for a battery with high power and low capacity, it can give a power in less time than a battery with high capacity and low power [58].

2.5.2 Depth Of Discharge (DOD)

Depth Of Discharge (DOD) is expressing the quantity of the capacity for the battery which being used. Most of the batteries should remain a charge in it because of its chemical side, if the battery is being used with a 100% of its charge, its life will be shorter. While the DOD for the battery is high, the capacity will be high too. The State Of Charge (SOC) has a negative relation with the depth of discharge (DOD). While the state of charge is increasing, the depth of discharge is decreasing, and vice versa, Figure 2.23 [57].

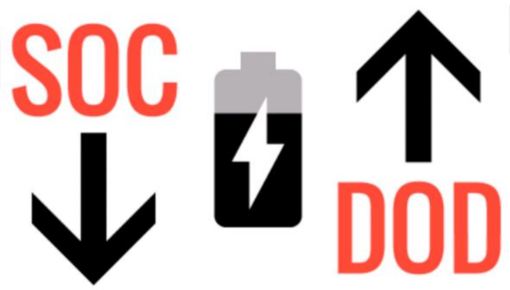


Figure 2.23 The inverse relation between the SOC and the DOD

2.5.3 Round Trip Efficiency

The round trip efficiency for the battery is the ratio of the output energy to the input energy. If the battery has an input of 10 kWh and the output is 9 kWh of electricity, the round trip efficiency will be (9 kWh / 10 kWh = 90%). As a result, for getting an economical selection of the battery, it should has a high round trip efficiency [12,58].

2.5.4 Battery Life Time

The life time of the battery has a negative relation with the depth of discharge. The more depth of discharge percentage, the less number of working years for the battery.

The working years of the battery called cycles. The next Figure 2.24 shows the graph between the depth of discharge and the number of cycles for a battery as an example [59].

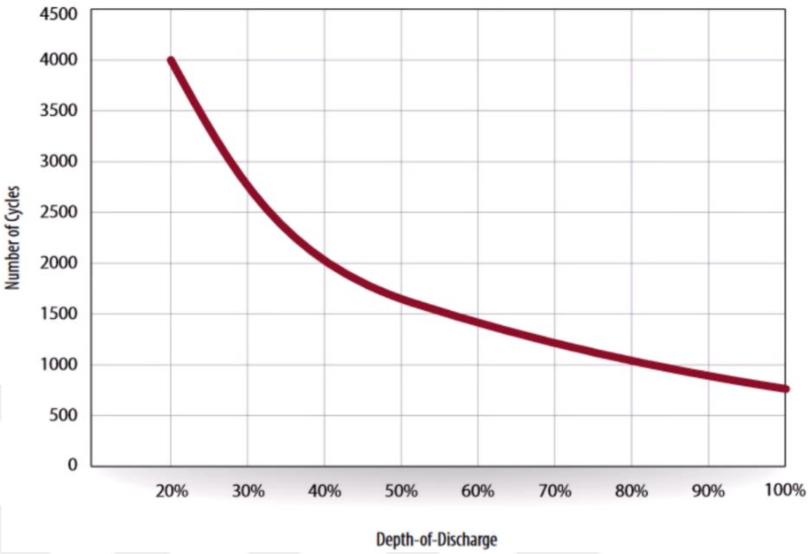


Figure 2.24 The negative relation between the depth of discharge and the number of cycles

Also, the life time of the battery is being affected by the surrounding temperature of the battery without paying attention if the battery is being used or not. As it is illustrated in Figure 2.25, in the temperature of 25^{O} C the life time of the battery will be almost 10 years. On the other hand, if the temperature is raised to be 40 ^{O} C or more, the life time of the battery will be reduced to be one or two years [60].

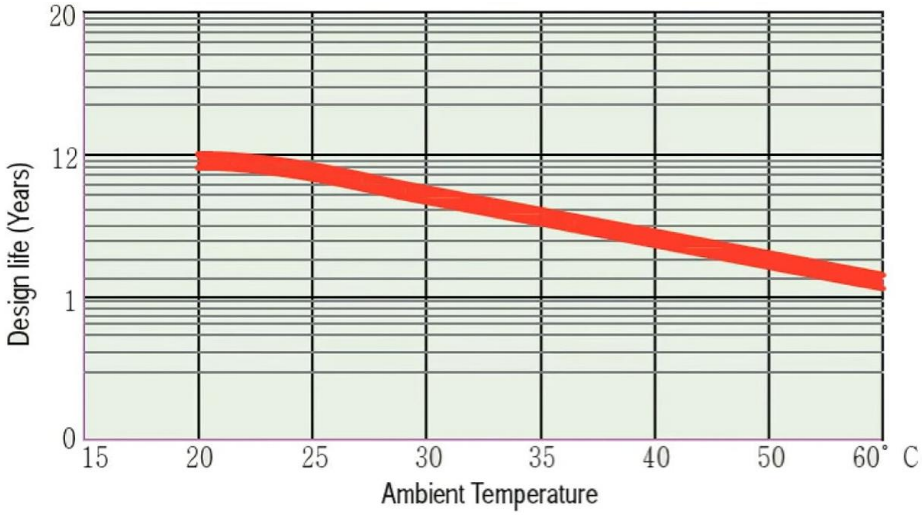


Figure 2.25 The life time of the battery and the ambient temperature

The lithium ion batteries are being used in the hybrid renewable energy systems as they have higher DOD by comparing the value of the percentage with the lead acid batteries, also they have longer life cycle. In addition, they are more compact and not heavy in the comparison with the lead acid batteries. On the other hand and according to the features of the lithium ion battery, obviously it will be expensive [58].

The lead acid batteries are also being used in the hybrid renewable energy systems for a long time. They are cheaper than the lithium ion batteries according to their specifications which are shorter life time and lower DOD [58].

The lead-acid battery has two electrodes, positive and negative. The positive electrode is lead dioxide (PbO_2) and the negative electrode is pure lead (Pb). Between the two electrodes, a diluted sulphuric acid (H_2SO_4) is filled. The nominal cell voltage is 2V, therefore, a 12V battery will has 6 cells each of them has 2V. It can be found with an amplitude of 6V, 12V and 24V [56].

For the zinc bromine flow battery, its depth of discharge (DOD) is one hundred percent and it has no shelf life limitations because it is nonperishable. Also, it has the ability to be scaled according to its capacity [61].

2.6 The Diesel Generator

In the hybrid PV / Wind system, a backup diesel generator is being used to feed the electrical load. It is called backup generator because it will be used in some cases like in the cloudy days so the PV panels will not produce enough electricity to provide the electrical load, the days that the wind speed is less than the usual speed to produce the electrical energy from the wind turbines and in other cases like to supply the peak of the electrical load or when the batteries' charge is insufficient to supply the load with the electrical energy. In other words, the backup diesel generator is a way to improve the hybrid system from the side of the electrical energy production and make it better and more stable in special cases which were explained previously. Put another way, a backup diesel generator is being used to fill the lack of the electricity which is required by the load in a continuous way side by side to the hybrid PV / Wind system. Figure 2.26 shows the a real hybrid PV / Wind energy system with a backup ganerator which is being used in Winterbach in Germany [1,12,62].

Figure 2.26 A hybrid PV / Wind energy system with diesel generator

To make the generator able to act like that, it should be selected to be able to handle all the previous cases. Also, the changes of the climate must be considered because it is an important factor which is affecting the diesel generator in a positive or negative way. In addition, according to the growing of the electrical energy demand day by day, so this side should not be forgotten. Another factor has to be taken into account which is the fuel and the ability to provide the requested amount to the diesel generator, which will cost a lot if the area where the diesel generator will be installed in is isolated or far away from the common or state areas because the fuel will be transferred into those areas which will affect negatively on the price of the fuel [1,63].

The use of the diesel generator in the hybrid PV / Wind system will reduce the needs of the fuel which is being used because all of the components of the hybrid system will work together according to the conditions of the climate to supply the needy electricity to the electrical load. In this case, the fuel emissions will also be reduced according to the use of the other renewable resources and it will affect in a positive way to the mother nature.

CHAPTER 3

THE ANALYSIS OF THE SOLAR AND WIND RESOURCES

3.1 Location Selection

The selection of the area was accomplished by considering the best data of the solar radiation and wind speed possibilities of two regions in Turkey which are located in Ankara and Izmir. According to the NASA surface meteorology and solar energy database, the mentioned regions have a high solar radiation and wind speed possibilities. The next areas were selected for further studies and analysis:

- Cubuk / Ankara – Turkey.
- Urla / Izmir – Turkey.

In Figure 3.1, it is obvious that the mean yearly global radiation in Turkey has the highest value in the southwest areas which are near Izmir city that were colored with red color like Urla area with a 1800 – 1900 (kWh m^{-2}) solar radiation. The medium value of the solar radiation is located in the middle of Turkey which has the light blue color like Ankara city with a solar radiation of 1500 – 1600 (kWh m^{-2}) [64].

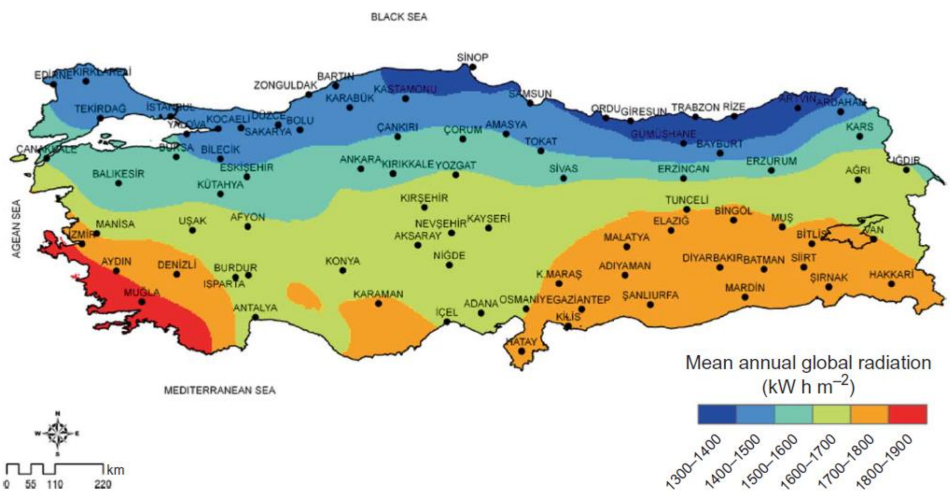


Figure 3.1 The solar radiation all over Turkey

The wind power density map in Turkey is illustrated in Figure 3.2, the highest values of the wind power density are available in the western side of Turkey like Izmir city as it is shown on the map, on the other hand, the wind power density in Ankara is less than Izmir as it is shown in the next figure. The wind power density is the availability of the power per square meter of the turbine according to its swept area. It can be calculated in a different height values off ground [65-66].

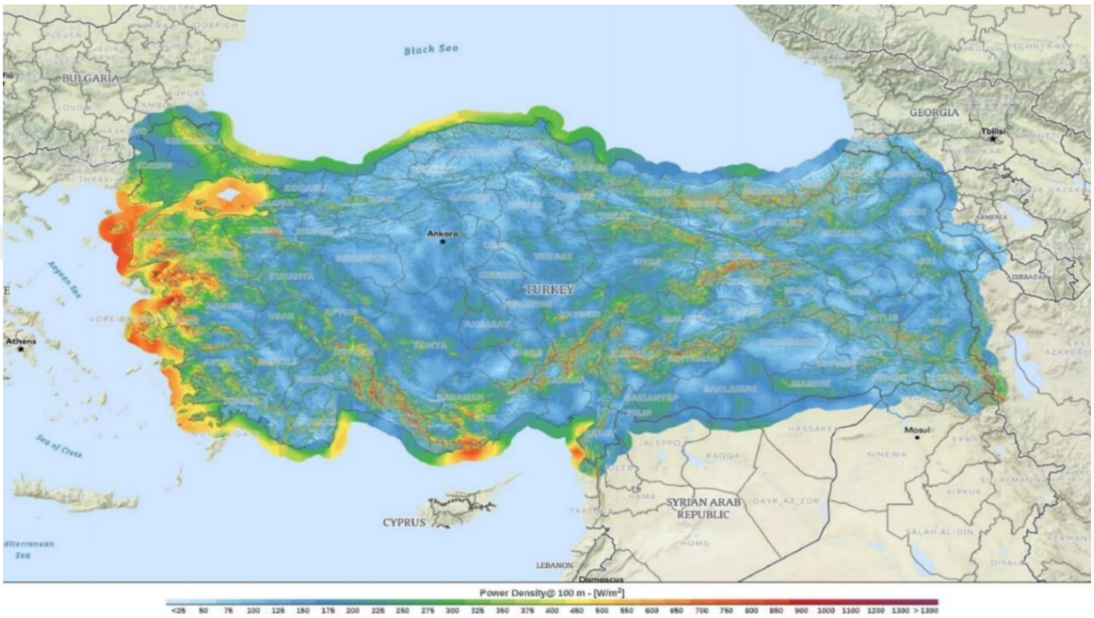


Figure 3.2 The wind power density map in Turkey

3.2 The Analysation of Solar Energy Possibility in Cubuk / Ankara

According to NASA surface meteorology and solar energy database, the average values of the solar radiation per month in Cubuk is as it is shown in Table 3.1. Figure 3.3 shows the average of the solar radiation values for the selected place. It is obvious from the figure that the highest solar radiation is happening in June and July which are in summer season.

Table 3.1 The monthly solar radiation

Month	Daily radiation (kWh/m^2/day)
January	1.770
February	2.500
March	3.730
April	4.480
May	5.690
June	6.440
July	6.750
August	5.990
September	4.840
October	3.260
November	2.070
December	1.490
Annual average	4.08

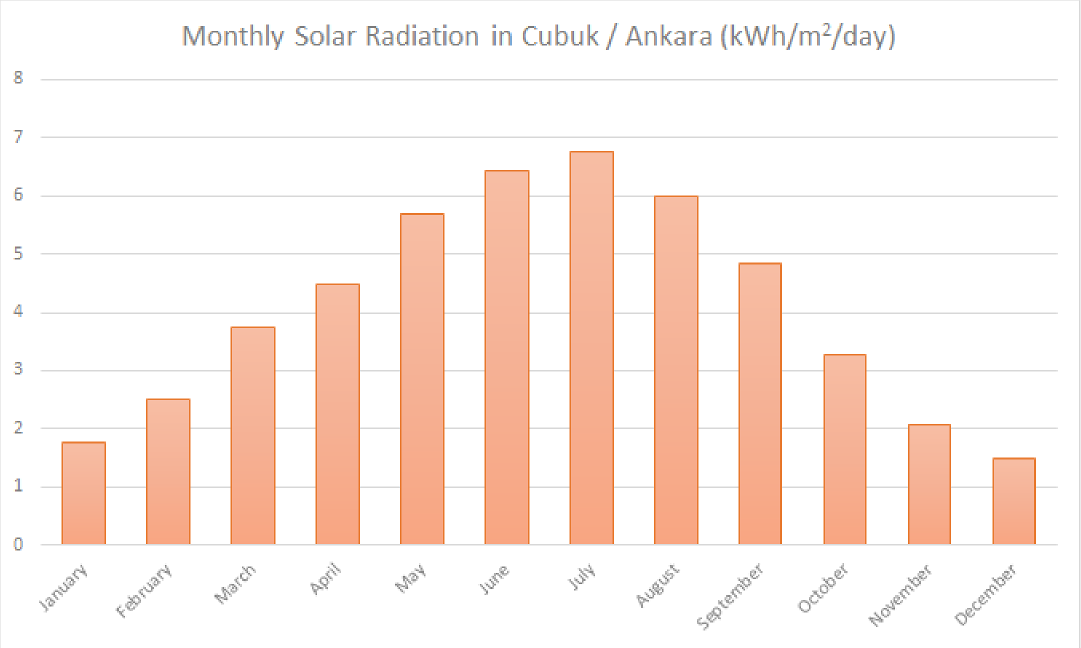


Figure 3.3 The monthly solar radiation in Cubuk / Ankara

3.3 The Analysation of Wind Energy Possibility in Cubuk / Ankara

For the wind speed data of the selected place, Table 3.2 shows the average wind speed per month at height of 50 m. The yearly average of the wind speed is equal to 4.75 (m/s) and it is in the range of (3.88 – 5.43) (m/s). The data were taken from NASA surface meteorology and solar energy database.

Table 3.2 The monthly wind speed

Month	Average wind speed (m/s)
January	5.530
February	5.430
March	4.660
April	4.310
May	3.920
June	3.880
July	4.550
August	4.930
September	4.650
October	4.720
November	5.040
December	5.390
Annual average	4.75

Figure 3.4 illustrates the wind speed data per month for the selected place at the height of 50 m. As it is noticeable, the highest speed of the wind is happening in January, February and December which are in winter season.

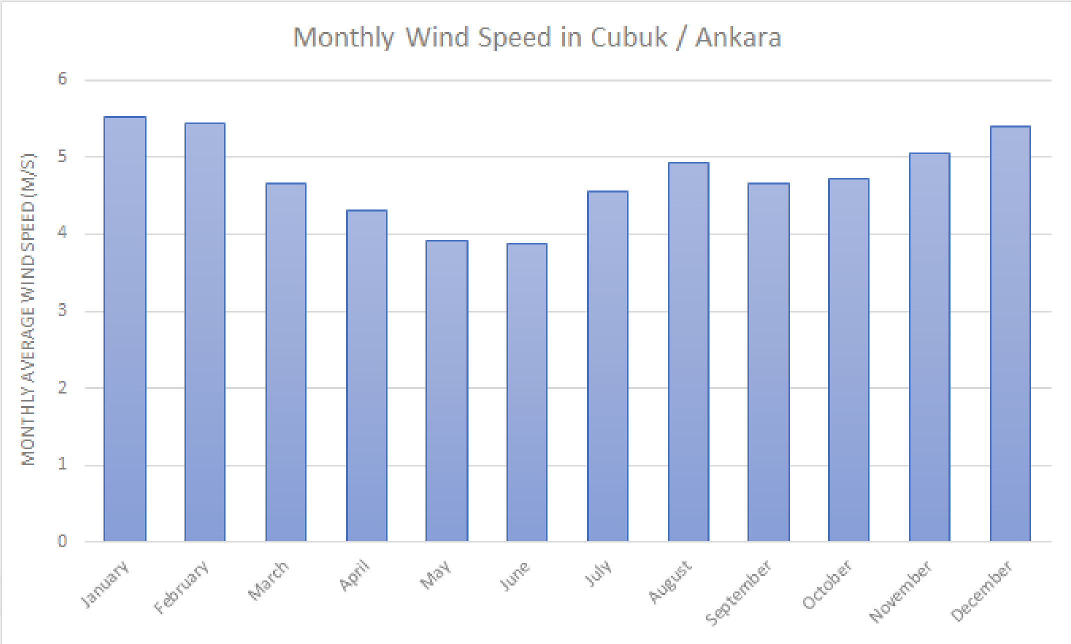


Figure 3.4 The monthly wind speed in Cubuk / Ankara

3.4 The Analysation of Solar Energy Possibility in Urla / Izmir

In Urla, the average values of the solar radiation per month according to NASA surface meteorology and solar energy database is shown in Table 3.3. The yearly average value of the solar radiation is equal to 5.08 (kWh/m^2/day).

Table 3.3 The monthly solar radiation

Month	Daily radiation (kWh/m^2/day)
January	2.170
February	3.030
March	4.430
April	5.820
May	7.280
June	8.340
July	8.230
August	7.340
September	5.860
October	4.070

November	2.560
December	1.820
Annual average	5.08

Figure 3.5 shows the average of the solar radiation values for the selected place. It is obvious from the figure that the highest solar radiation is happening in June and July which are in summer season.

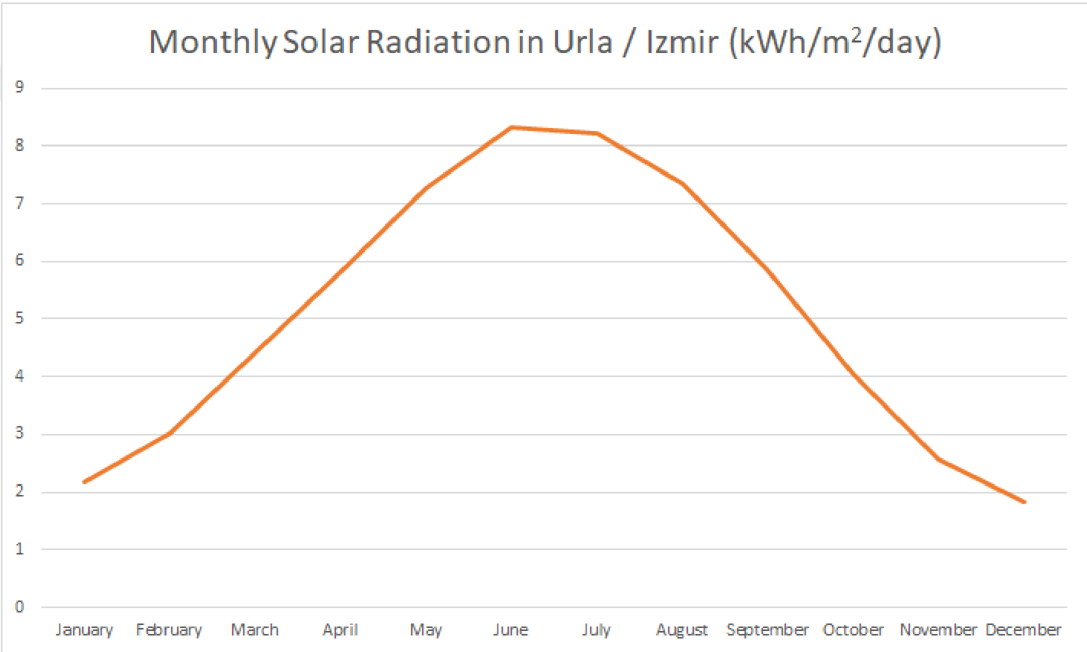


Figure 3.5 The monthly solar radiation in Urla / Izmir

3.5 The Analysation of Wind Energy Possibility in Urla / Izmir

The wind speed data per month for the selected place at the height of 50 m is shown in Figure 3.6. It is clear that the wind speed has a high value almost all the year. The data were taken from NASA surface meteorology and solar energy database.

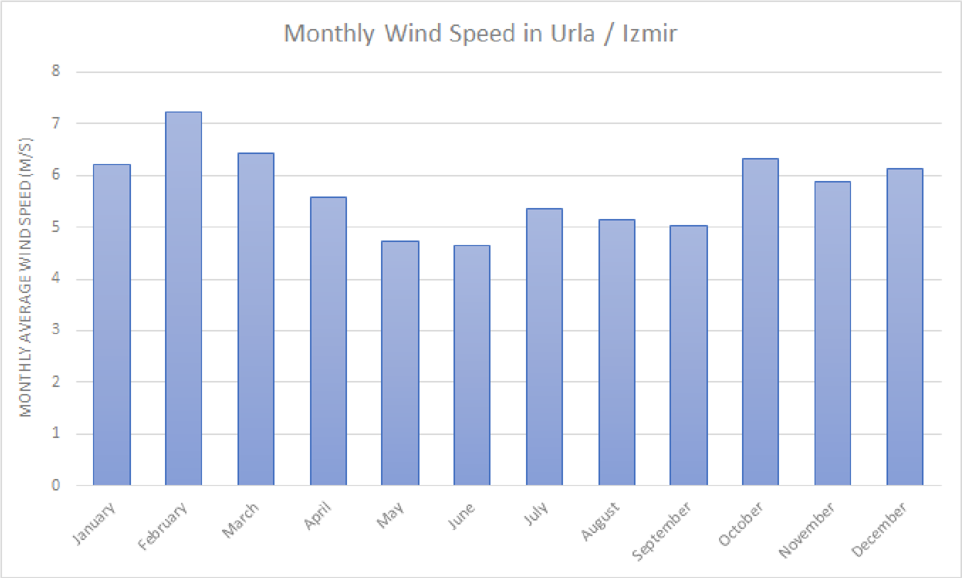


Figure 3.6 The monthly wind speed in Urla / Izmir

For the wind speed data of the selected place, Table 3.4 shows the average wind speed per month at height of 50 m. The yearly average of the wind speed is equal to 5.72 (m/s) and it is in the range of (4.65 – 7.22) (m/s).

Table 3.4 The monthly wind speed

Month	Average wind speed (m/s)
January	6.210
February	7.220
March	6.430
April	5.570
May	4.740
June	4.650
July	5.350
August	5.150
September	5.020
October	6.310
November	5.880
December	6.140
Annual average	5.72

CHAPTER 4

THE DESIGN OF THE HYBRID SYSTEM

4.1 Load Profile

The selection of the load profile is an important step to do because the rest of the hybrid system's components will be chosen according to the load profile. The load profile in this study is a community area where two hundred persons are living in it. The demand of the electrical energy is stable all over the year. The load will be as it is shown in Table 4.1 according to the working hours of the devices in every day from 00:00 until 23:00.

Table 4.1 The Load Demand

Time	Load (kW)	Time	Load (kW)
00:00	112.110	12:00	118.779
01:00	112.110	13:00	127.714
02:00	112.110	14:00	127.671
03:00	112.110	15:00	125.579
04:00	137.742	16:00	135.191
05:00	231.037	17:00	151.211
06:00	209.000	18:00	146.024
07:00	115.718	19:00	118.766
08:00	167.428	20:00	170.091
09:00	160.944	21:00	177.749
10:00	151.211	22:00	186.889
11:00	151.211	23:00	184.274

The next Figure 4.1 shows the daily load profile during the day. It has various values because the demand of the electrical energy is changing during the day according to the devices and places that is requiring electrical energy in some specific hours in the day.

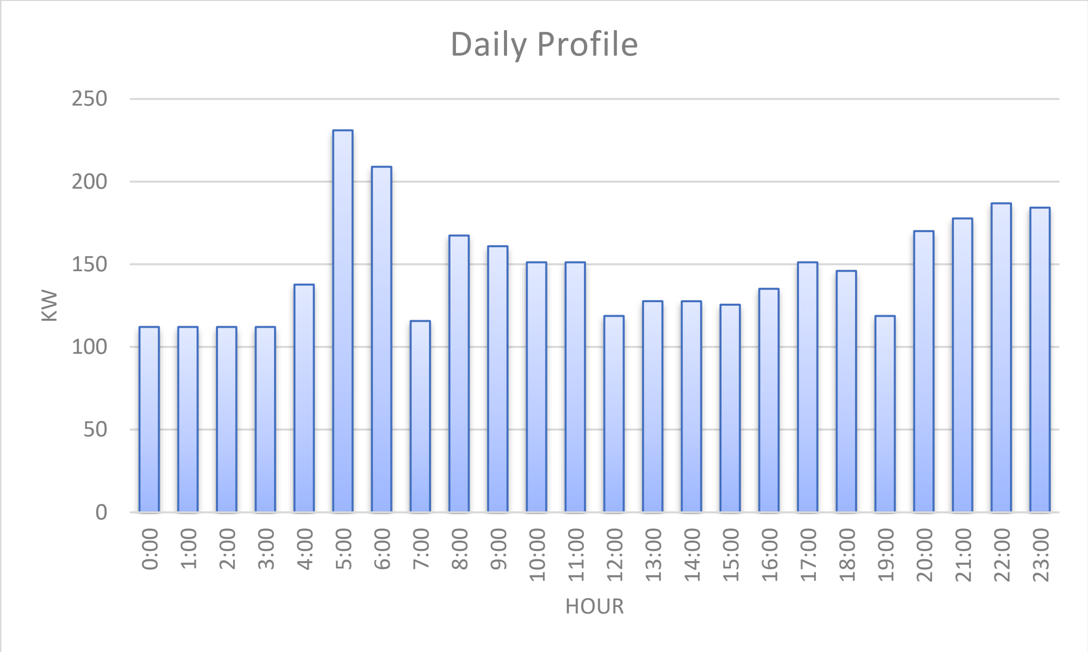


Figure 4.1 The daily load profile

The hybrid PV / Wind system is designed to supply the required energy to the community load which were illustrated in the previous Figure 4.1 by using HOMER program by making the simulation to the whole system.

4.2 The Hybrid PV / Wind Power System

The system which utilize the electrical power which is being produced from more than one resource is well-known as a hybrid system. In this thesis, the proposed hybrid system is consisting of photovoltaic (PV) modules and wind turbine generators with some other devices like the power converter. By using the photovoltaic modules besides the wind turbines, the reliability will be much better than using each of them alone because it is not possible to count on one power resource at any time, in any case [14].

In this thesis, the proposed hybrid system is a PV / wind hybrid system which is producing electrical power from the solar PV modules and the wind turbine. The hybrid PV / wind power system is illustrated in the next Figure 4.2 [14].

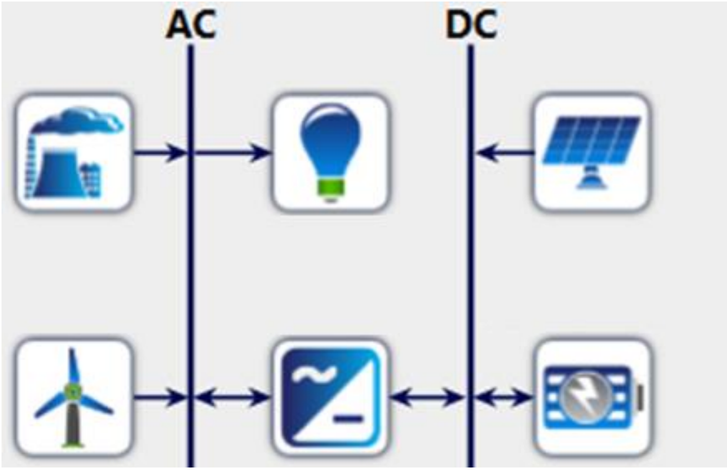


Figure 4.2 The hybrid PV / wind power system

4.3 HOMER Software

HOMER software is a short name of the Hybrid Optimization Model for Electrical Renewable software. US National Renewable Energy Laboratory (NREL) developed it in the United States, Figure 4.3 [14,67]. HOMER is offering many options to be used to make the technically and financially studies for the off-grid and on-grid power systems [68].

Figure 4.3 Hybrid Optimization Model for Electrical Renewable (HOMER)

Some of the functions that HOMER software is used for are: the simulation, optimization and making the analysation for the sensitivity of the data which the user will input it to the software. The simulation can be performed on many energy resources like photovoltaic arrays, wind turbines, battery banks, generators and loads [68].

The simulation part makes the imagination of the proposed hybrid power system much easier in terms of the making sure that the proposed hybrid power system is suitable to build and install. Another good feature, the simulation calculates the cost of the whole system depending on the inputted data, as a result, the software will give and suggest the best system to install according to its cost [68].

4.4 The Locations And Their Parameters

The main aim of the thesis is to make a hybrid PV / Wind system in the area, which contain the community load, to supply the load with the required electrical energy from the renewable resources without the need of the state electricity.

As mentioned in the previous chapter, the possibility of solar radiation and wind speed were studied for two locations which are Cubuk / Ankara and Urla / Izmir.

Depending on the results of the previous studies and their data, Urla region which is located in Izmir was found that it is very suitable to take it as a location work of the project according to its high solar radiation and high wind speed which will lead to a better electrical energy production. To design the hybrid PV / wind energy system, a comparison will be done between Cubuk and Urla. Cubuk is located in the northern side of Ankara near Ankara Esenboga Airport as shown in Figure 4.4, while Urla is located in the western side of Izmir city as it is illustrated in Figure 4.5.

Figure 4.4 The place of the selected area in general in Cubuk

Figure 4.5 The place of the selected area in general in Urla

The specific location in Cubuk is marked with the red marker as shown in Figure 4.6. The longitude and the latitude are 32°56`E, 40°7`N respectively.

The specific location in Urla is marked with the red marker as shown in Figure 4.7. The longitude and the latitude are 26°36`E, 38°17`N respectively.

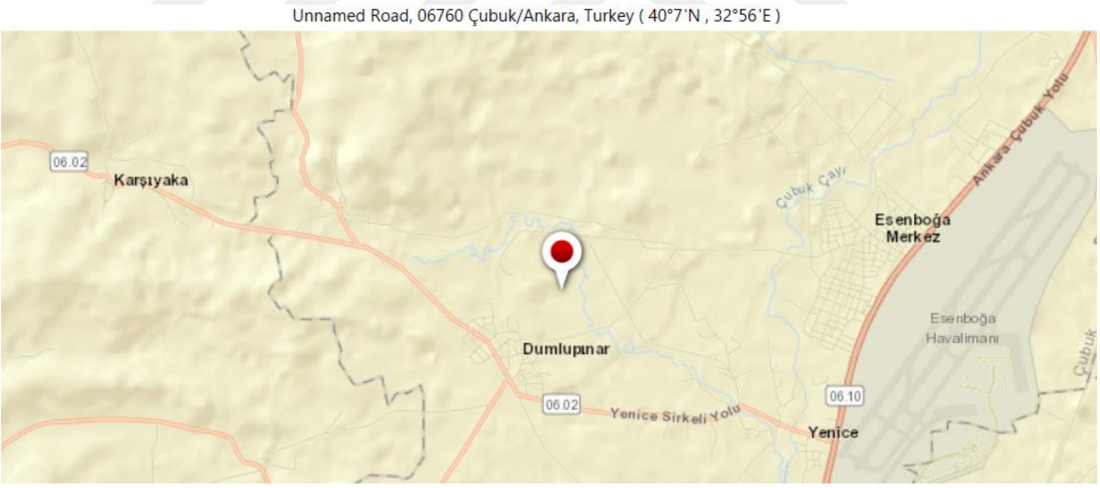


Figure 4.6 The selected location in Cubuk

Figure 4.7 The selected location in Urla

For the selected locations, HOMER program has an advantage of getting the data of the solar irradiance, wind speed and some other renewable energy resources online from the NASA surface meteorology and solar energy database depending on the selected location and its longitude and latitude values.

4.4.1 The Parameters For Cubuk

4.4.1.1 The Solar Irradiance Values

NASA surface meteorology and solar energy database feature which is available in HOMER program is offering the advantage of getting the average solar irradiance values, which is being measured by the unit of (kWh/m^2), and the clearness index values for each month for the selected location online and download it to be usable. The clearness index is expressing the clarity of the atmosphere and it has a value between 0 and 1 only, it is the amount of the solar radiation which is coming to the earth's surface after passing through the atmosphere layers towards the earth. The next Table 4.2 is showing the values of the clearness index and the average of the daily radiation for every month for a year. The average daily radiation is ranging between 1.49 and 6.75 (kWh/m^2/day) with a yearly average of 4.08 (kWh/m^2/day) for the selected location which is Cubuk.

Table 4.2 The monthly average solar irradiance and clearness index

Month	Clearness index	Daily radiation ($kWh/m^2/day$)
January	0.420	1.770
February	0.445	2.500
March	0.491	3.730
April	0.466	4.480
May	0.516	5.690
June	0.556	6.440
July	0.598	6.750
August	0.592	5.990
September	0.585	4.840
October	0.527	3.260
November	0.458	2.070
December	0.393	1.490

To find out the average of the clearness index for a year, the sum of the clearness index values must be calculated and divided by the total number of months which is 12 and the result will be equal to 0.5.

The average solar irradiance in ($kWh/m^2/day$) for each month from the left axis side, and also represents the clearness index with the months from the right axis side as it is illustrated in Figure 4.8.

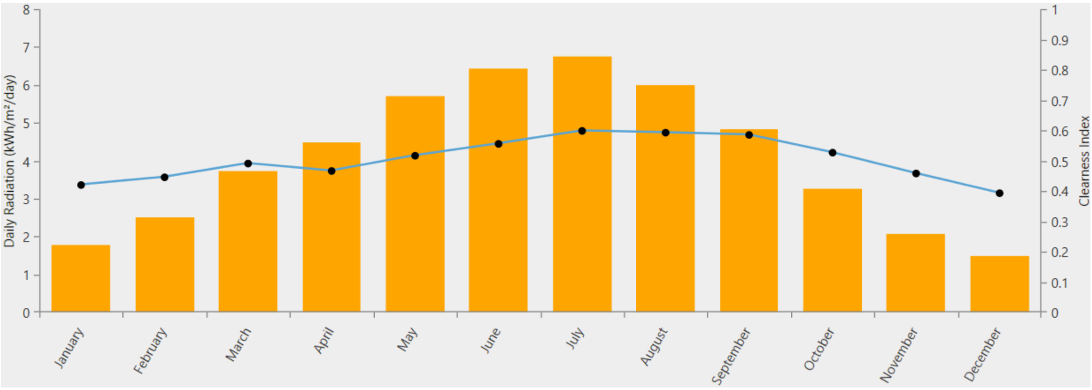


Figure 4.8 The monthly average solar irradiance data and clearness index

4.4.1.2 The Wind Speed Values

For the wind speed data, it could be downloaded also online by using the feature in HOMER program. It is offering the average wind speed data for every month depending on the NASA surface meteorology and solar energy database.

The next Table 4.3 is showing the wind speed average values for each month separately at a height of 50 m above the ground. The wind speed values for the selected location, which is Cubuk, are differs between 3.88 and 5.53 (m/s).

Table 4.3 The monthly average wind speed

Month	Average (m/s)
January	5.530
February	5.430
March	4.660
April	4.310
May	3.920
June	3.880
July	4.550
August	4.930
September	4.650
October	4.720
November	5.040
December	5.390

It is obvious that the annual average of the wind speed will be the sum of the wind speed values divided by the number of the months which is 12 and it will equal to 4.75 (m/s). Figure 4.9 represents the average wind speed in (m/s) for each month.

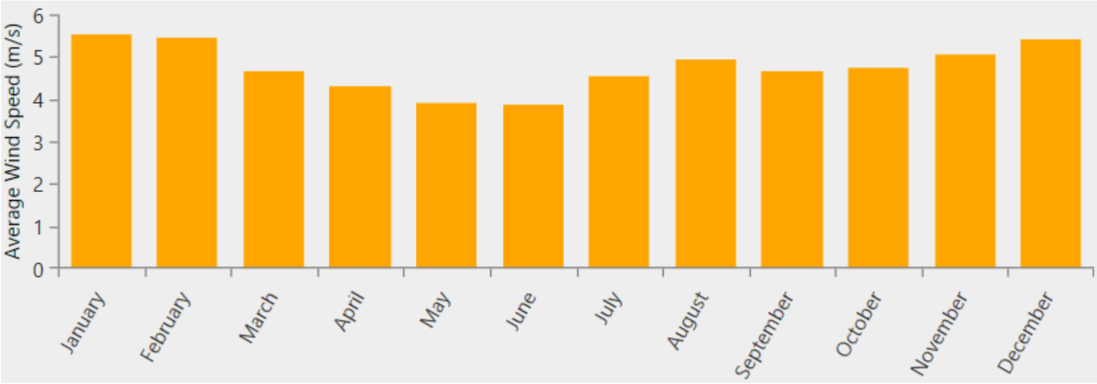


Figure 4.9 The monthly average wind speed data

4.4.2 The Parameters For Urla

4.4.2.1 The Solar Irradiance Values

NASA surface meteorology and solar energy database feature which is available in HOMER program is offering the advantage of getting the average solar irradiance values, which is being measured by the unit of (kWh/m^2), and the clearness index values for each month for the selected location online and download it to be usable. The clearness index is expressing the clarity of the atmosphere and it has a value between 0 and 1 only, it is the amount of the solar radiation which is coming to the earth's surface after passing through the atmosphere layers towards the earth. The next Table 4.4 is showing the values of the clearness index and the average of the daily radiation for every month for a year. The average daily radiation is ranging between 1.82 and 7.34 (kWh/m^2/day) with a yearly average of 5.08 (kWh/m^2/day) for the selected location which is Urla.

Table 4.4 The monthly average solar irradiance and clearness index

Month	Clearness index	Daily radiation (kWh/m^2/day)
January	0.479	2.170
February	0.513	3.030
March	0.566	4.430
April	0.597	5.820

May	0.658	7.280
June	0.720	8.340
July	0.729	8.230
August	0.719	7.340
September	0.692	5.860
October	0.630	4.070
November	0.530	2.560
December	0.443	1.820

To find out the average of the clearness index for a year, the sum of the clearness index values must be calculated and divided by the total number of months which is 12 and the result will be equal to 0.6.

The average solar irradiance in (kWh/m^2/day) for each month from the left axis side, and also represents the clearness index with the months from the right axis side as it is illustrated in Figure 4.10.

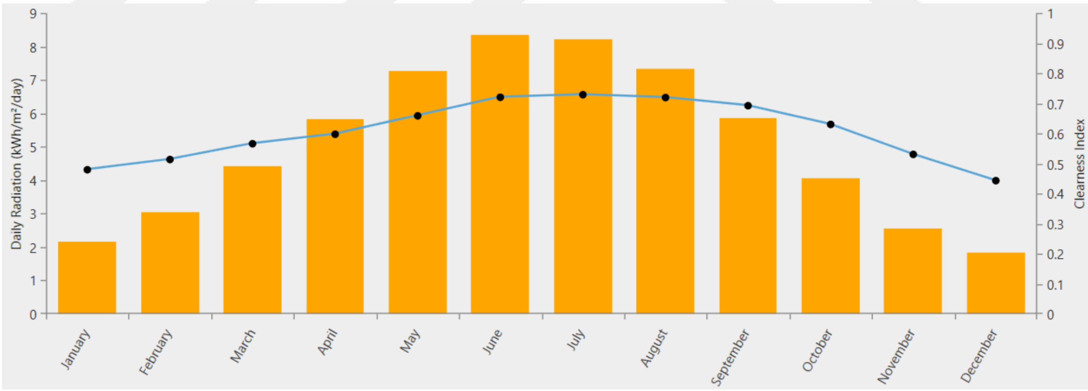


Figure 4.10 The monthly average solar irradiance data and clearness index

4.4.2.2 The Wind Speed Values

For the wind speed data, it could be downloaded also online by using the feature in HOMER program. It is offering the average wind speed data for every month depending on the NASA surface meteorology and solar energy database.

The next Table 4.5 is showing the wind speed average values for each month separately at a height of 50 m above the ground. The wind speed values for the selected location which is Urla are differs between 4.65 and 7.22 (m/s).

Table 4.5 The monthly average wind speed

Month	Average (m/s)
January	6.210
February	7.220
March	6.430
April	5.570
May	4.740
June	4.650
July	5.350
August	5.150
September	5.020
October	6.310
November	5.880
December	6.140

It is obvious that the annual average of the wind speed will be the sum of the wind speed values divided by the number of the months which is 12 and it will equal to 5.72 (m/s). Figure 4.11 represents the average wind speed in (m/s) for each month.

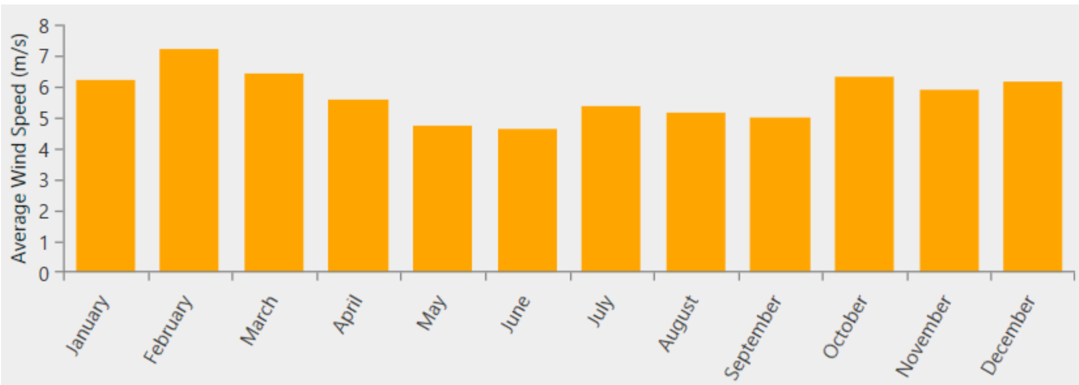


Figure 4.11 The monthly average wind speed data

4.5 Selection Of The PV Panel

In the selection of the PV panel which will be used, there are some conditions must be taken into considiratin to get the highest electrical energy production in the selected location and to be also effective in the hybrid PV / Wind system. Some of the factors of the PV panel which cannot be ignored are the capacity of the PV panel, the type of the PV model whether it is mono-crystalline or poly-crystalline, the life time, the efficiency of the PV panel and some other factors. The chosen PV panel is generating the electrical energy in the direct current DC type with more than one size, the sizes of the PV panel will be considered to be between 700 – 1,300 kW. After HOMER program makes the simulation, it will suggest the ideal size of the PV panel to be used. The selected PV panel is produced by Canadian Solar company with a model of Quintech CS6K-285M. It has 60 mono-crystalline cells with a nominal max power of 285 W. The specifications of the suggested PV model are illustrated in the next Table 4.6.

Table 4.6 Quintech CS6K-285M specifications

Nominal max. Power	285 (W)
Opt. Operating voltage (V_{mp})	31.7 (V)
Opt. Operating current (I_{mp})	8.98 (A)
Open circuit voltage (V_{oc})	38.6 (V)
Short circuit current (I_{sc})	9.51 (A)
Module efficiency	17.41%
Cell efficiency	20.0%
Cell arrangement	60 cells
Design life	25 years

The I-V curve of the chosen Quintech CS6K-285M is illustrated in Figure 4.12 and it is available in the datasheet of the model. The under standard test conditions (STC) of irradiance of 1000 W/m^2, spectrum airmass 1.5 and cell temperature of 25^oC.

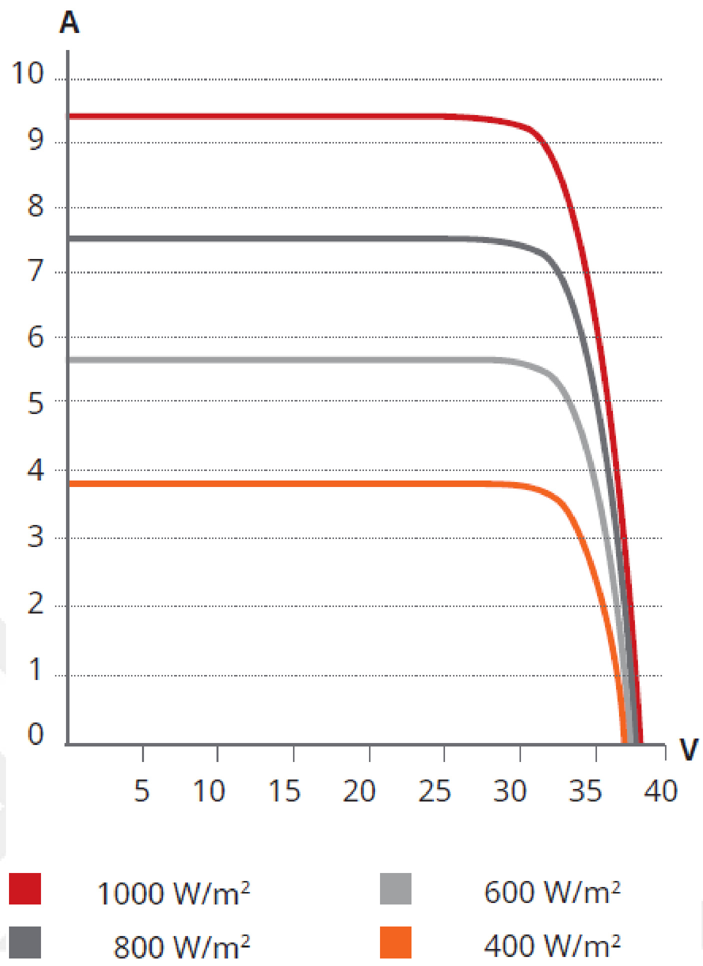


Figure 4.12 The I-V curve of the quintech CS6K-285M

The capital cost for 1 kW electrical power which is being produced by the solar panels will be approximately 500 US dollar. The operation and maintenance cost (O&M) will be 1% of the capital cost for every year which is equal to 5 US dollar [69-70]. For the replacement cost, it will be 70% of the capital cost, for that it will be equal to 350 US dollar.

4.6 Selection Of The Wind Turbine

According to the wind speed of the selected location, the electrical energy production of the wind turbine must be effective in the hybrid PV / Wind system and it can be done by using a single wind turbine with high energy production or by using a group of small wind turbines with less energy production. There are some important factors must be considered while choosing the wind turbine like the capacity, life time, cut-in wind speed, rated wind speed, tower height and some other factors. The chosen wind turbine is generating the electrical energy in the alternating current AC type with a rated power of 250 kW. The selected wind turbine is produced by wind energy solutions (WES) company with a model of WES-250. The specifications of the suggested wind turbine are illustrated in the next Table 4.7.

Table 4.7 WES-250 wind turbine specifications

Rated power	250.0 (kW)
Rotor diameter	30.0 (m)
Swept area	707.0 (m^2)
Hub height	48 (m)
Cut-in wind speed	3 (m/s)
Rated wind speed	13 (m/s)
Cut-out wind speed	25 (m/s)
Design life	20 years minimum

The static power curve of the chosen wind turbine is shown in Figure 4.13 and it is given by the HOMER program.

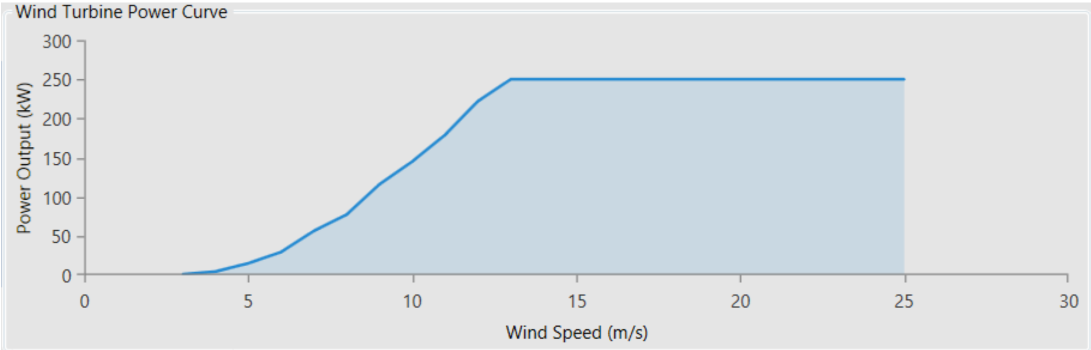


Figure 4.13 The static power curve of the wind turbine

The output power of the wind turbine is being illustrated in Table 4.8 according to the wind speed values at the hub height of 48 meters.

Table 4.8 Power production of the wind turbine according to the wind speed values

Wind speed (m/s)	Power (kW)
2	0.0
3	1
4	4.4
5	14.9
6	29.3
7	56.3
8	77.2
9	115.8
10	145
11	179
12	222
13	250
15	250
20	250
25	250

The complete cost of the wind turbines' installation was evaluated depending on the prices of the wind turbines which were installed in China and Europe since 2011 [71-72]. The capital cost in China was between 1,050 – 1,350 US dollar for 1 kW. In this thesis, the capital cost was chosen to be about 1,050 US dollar and for the the selected wind turbine which is producing 250 kW electrical power, the capital cost will be approximately 262,500 US dollar. The operation and maintenance cost (O&M) will be 2% of the capital cost for every year which means that it will be equal to 5,250 US dollar. For the replacement cost, it will be 70% of the capital cost, for that it will be equal to 183,750 US dollar.

4.7 Selection Of The Converter

By the selecting of the converter, a lot of models can be found in the HOMER library, it has a large catalog which is well organised according to the capacity of the converter or the inverter and some other factors. In this study, a bidirectional converter must be chosen because there are two different energy resources which are the DC resource and the AC resource to be able to charge the battery and at the same time to be able to use the power from the battery and convert it to AC. A model from ASEA Brown Boveri (ABB) company was chosen with a number of ABB MGS100 which has a capacity of 60kW. The next Table 4.9 is showing the converter specifications.

Table 4.9 The ABB MGS100 specifications

Capacity	60 (kW)
Inverter efficiency	95%
Rectifier efficiency	95%
Lifetime	15 years

The capital cost of the selected converter for 1 kW is approximately 400 US dollar, the operation and maintenance cost (O&M) will be 2% of the capital cost for every year which is equal to 8 US dollar and for the replacement cost it will be 70% of the capital cost which means it will be around 280 US dollar.

4.8 Selection Of The Battery

In the battery side, HOMER can suggest the number of the batteries which will be used after making the simulations. HOMER also has a library for the batteries with all of their specifications. For this study, a battery from Iron Edison Battery company was chosen with a name of Iron Edison LFP 2100Ah which is a Li-ion LFP battery with a lifetime of 15 years, and its abbreviation in HOMER software is Iron2100. The properties of the selected battery are shown in Table 4.10.

Table 4.10 The Iron Edison LFP 2100Ah properties

Nominal voltage	48 (V)
Nominal capacity	101 (kWh)
Maximum Capacity	2.1E+03 (Ah)
Roundtrip efficiency	95%
Maximum charge current	600 (A)
Maximum discharge current	600 (A)

The capital cost for one battery will be approximately 20,000 US dollar. For the replacement cost, it will be 70% of the capital cost, for that it will be equal to 14,000 US dollar. The operation and maintenance cost (O&M) will be 2% of the capital cost for every year which is equal to 400 US dollar.

4.9 Selection Of The Diesel Generator

In the deissel generator section, it should be chosen to act as a backup diesel generator in the hybrid system to be able to supply the peak of the load with the electrical energy besides the renewable energy resources. The diesel generator produces an AC energy and it will be connected to the AC bus in HOMER program. The selected diesel generator is from Caterpillar company with a power production of 320 kW with a model number of CAT-400kVA-50Hz-PP. The lifetime for the suggested diesel generator in hours will be 90 thousand hours, and after converting the hours to the years, it will be about ten years.

The diesel is costing in Turkey about 1 US dollar for one liter and the cost is changing according to the different values of the US dollar and for the remote areas the cost will be more expensive and it may be reach to be between 2 – 3 US dollar which will affect negatively on the system cost.

The capital cost for the diesel generator will be approximately 60,000 US dollar. For the replacement cost, it will be 70% of the capital cost, for that it will be equal to 42,000 US dollar. The operation and maintenance cost (O&M) per operating hour will be around 0.5 US dollar.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 The Discussion Of The Results

As mentioned before, the design of the model for the hybrid PV / wind system was done by using the trial version of Hybrid Optimization Model for Electrical Renewable (HOMER) software. The simulation and the optimization processes will be discussed next.

5.1.1 The Load Profile

As discussed previously, the load profile is a community load which has the seasonal profile as illustrated in Figure 5.1. The seasonal profile is showing the minimum, maximum and average load values for each month. The first line from the top it is expressing the maximum value for the month, the last line in the bottom is expressing the minimum value for the month. The upper side of the blue box is showing the average value for the maximum daily value and the lower side of the blue box is showing the average of the daily minimums. The line in the middle is for the average value for the full month, the expressions are illustrated as shown in Figure 5.2 [73]. The load has a scaled annual average of 3,542.68 kWh/day with a peak of 423.24 kW as shown in Figure 5.3.

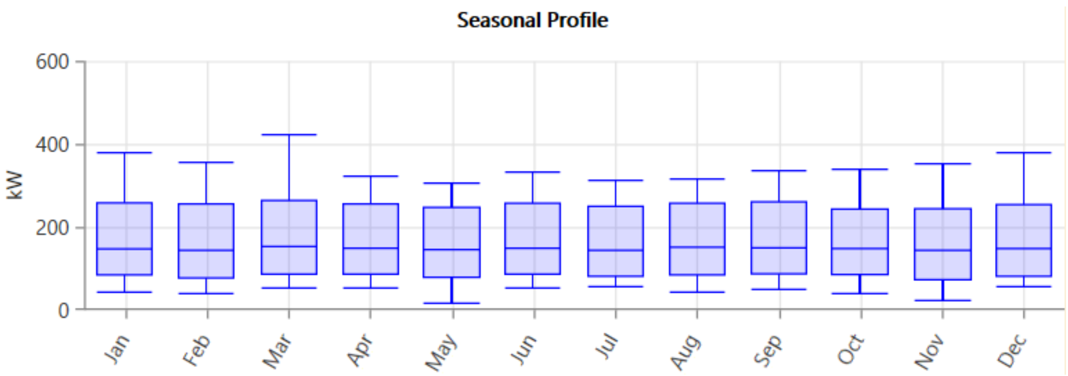


Figure 5.1 The seasonal profile for the load

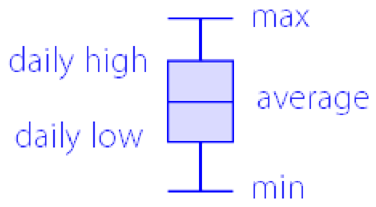


Figure 5.2 The expressions of the values

5.1.2 The Case Of Cubuk / Ankara

5.1.2.1 The Simulations Of The Systems

Figure 5.3 illustrates the schematic figures of the proposed hybrid systems with all of the components which were being used during the simulation by using HOMER software. In the schematic figures, the components have a short name, for the solar panel it is (CS6K-285M), for the wind turbine it is (WES250), for the diesel generator it is (CAT-400), for the battery it is (Iron2100) and for the converter it is (ABB-MGS).

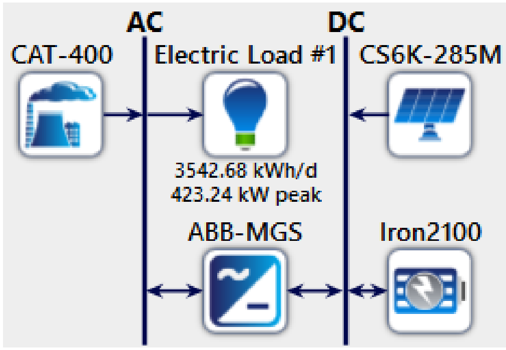
The simulation process included the capacities of the solar panels, wind turbines, batteries and financing costs with taking into consideration the lifetime of the components.

There are three hybrid systems proposed which are the hybrid PV / diesel energy system which is shown in Figure 5.3 (a), the hybrid wind / diesel energy system which is shown in Figure 5.3 (b) and the hybrid PV / wind / diesel energy system which is shown in Figure 5.3 (c).

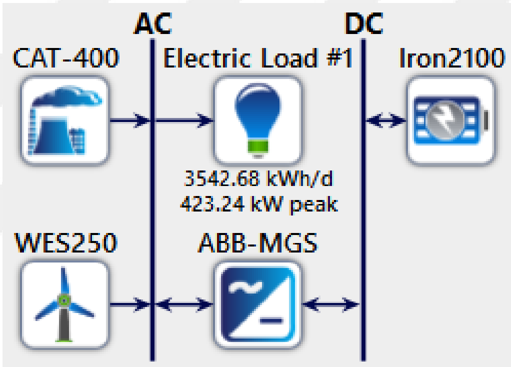
For the first case which is hybrid PV / diesel energy system that is shown in Figure 5.3 (a), the solar panels varied between 700 – 1300 kW, the batteries were between 0 and 100 battery. About the converter, it was between 60 and 360 kW.

And for the second case which is hybrid wind / diesel energy system that is shown in Figure 5.3 (b), the quantity of the wind turbines was from 1 to 8, and for the batteries it was between 0 and 100 battery. About the converter, it was between 60 and 360 kW.

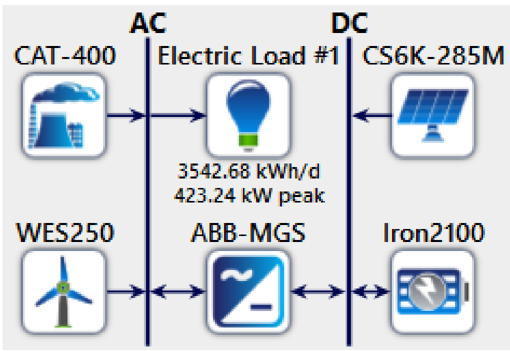
About the third case which is hybrid PV / wind / diesel energy system that is shown in Figure 5.3 (c), the solar panels varied between 700 – 1300 kW, for the wind turbines, the quantity of it was from 1 to 8. And for the batteries, it was between 0 and 100 battery. About the converter, it was between 60 and 360 kW.



(a)



(b)



(c)

Figure 5.3 The schematic figures of the proposed hybrid systems

(a) PV / diesel – (b) Wind / diesel – (c) PV / wind / diesel

5.1.2.2 The Optimization Results

After the simulation processes were done for all of the possible solutions for the proposed hybrid systems, HOMER shows the results in a list according to their cost of energy (COE), initial capital cost and net present cost (NPC).

Cost of energy (COE) is the definition which HOMER uses to calculate the average cost for every 1 kWh of the electrical energy which the system is producing [74].
Initial capital cost which is the sum of the cost for the installed components when the project starts.
Net present cost (NPC) of a component is the current value of all the installing and operating costs of the component over the project lifetime, minus the current value of all the profits that it earns over the project lifetime [75].

The categorized optimization results which HOMER offered are illustrated in Figure 5.4 for three hybrid systems.

- In the first system which is hybrid PV / diesel system that is shown in Figure 5.4 (a), the renewable fraction is 85.5%.
- In the second hybrid wind / diesel system which is illustrated in Figure 5.4 (b), the renewable fraction is 53.5%.
- For the third hybrid PV / wind / diesel system which is presented in Figure 5.4 (c), HOMER is suggesting two systems, a system by using the diesel generator and another system which is not using the diesel generator.

For the hybrid PV / wind / diesel system, It is obvious that the best system is the first one because it has the lowest cost of energy (COE) and net present cost (NPC), but on the other hand, the first system is using the renewable resources with a percentage of 90.6% which is the renewable fraction, unlike the second system which is using 100% of the renewable resources, but it is more expensive in comparison with the first system.

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System
CS6K-285M (kW)	CAT-400 (kW)	Iron2100	ABB-MGS (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
1,300	320	32	300	LF	$0.161	$2.69M	$94,614	$1.47M	85.5

(a)

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System
WES250	CAT-400 (kW)	Iron2100	ABB-MGS (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
4	320	17	300	LF	$0.280	$4.68M	$240,867	$1.57M	53.5

(b)

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture						Cost				System
CS6K-285M (kW)	WES250	CAT-400 (kW)	Iron2100	ABB-MGS (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
1,200	1	320	30	300	LF	$0.159	$2.66M	$78,748	$1.64M	90.6
900	4		100	360	CC	$0.268	$4.47M	$63,993	$3.64M	100

(c)

Figure 5.4 The categorized optimization results of HOMER for the proposed hybrid systems (a) PV / diesel – (b) Wind / diesel – (c) PV / wind / diesel

From the previous Figure 5.4, the cost of energy (COE) and the initial capital cost for the three systems can be noticed.

- For the first case in Figure 5.4 (a), the hybrid PV / diesel system contains 1,300 kW solar panels, one generator with 320 kW and 32 battery. The cost of energy (COE) is equal to 0.161 US dollar for 1 kW and the initial capital cost is 1.47 million dollar.
- The second case which is illustrated in Figure 5.4 (b), the hybrid wind / diesel system is composed of four wind turbines, one generator with 320 kW and 17 battery. The cost of energy (COE) is equal to 0.280 US dollar for 1 kW and the initial capital cost is 1.57 million dollar.
- The third system which is the hybrid PV / wind / diesel system, is divided into two suggestions from HOMER software.

The first proposed system consists of 1,200 kW solar panels, one wind turbines, one generator with 320 kW and 30 battery. It has the lowest cost of energy (COE) which is equal to 0.159 US dollar for 1 kW and the system's initial capital cost is 1,64 million dollar. It can be noticed that the renewable fraction in this case is equal to 90.6%.

On the other hand and for the second proposed system, the system consists of 900 kW solar panels, 4 wind turbines and 100 battery. This system is a little bit more expensive than the first system in the terms of using more solar panels, wind turbines and batteries, the cost of energy (COE) in this case is 0.268 US dollar for 1 kW and the system's initial capital cost is 3.64 million dollar. Also, the diesel generator is not being used which makes the system depending on the renewable resources 100%, for that, the renewable fraction here is 100%.

The previous results are expressing that the third system which is the hybrid PV / wind / diesel system has the lowest cost of energy (COE) among the three systems, and for that reason, it is the best system to be chosen.

5.1.2.3 The Optimization Results For The Hybrid PV / Wind / Diesel System

The simulation's results for the hybrid PV / wind / diesel system, which HOMER suggested, are listed in Table 5.1 and Table 5.2 respectively with the electrical power generated from the components in each system per year and their percentage.

The first hybrid system is producing a yearly electric energy with an approximate value of 2,107 GWh, the PV system is producing 82.9% of the total energy, the wind turbines are producing 11.3% of the total energy and the diesel generator is producing 5.76% of the total energy as it is shown in Table 5.1.

Table 5.1 The electrical power production for the first system

Production	kWh/year	Percentage %
Solar panel	1,746,596	82.9
Wind turbine	239,057	11.3
Diesel generator	121,288	5.76
Total	2,106,940	100

In the second system, HOMER proposed the system without the use of the diesel generator, in that case, the energy production from the second system is 100% clean energy because it is producing from the renewable resources without the need of the diesel generator. The total energy in this system is approximately of 2,266 GWh, the PV system is producing 57.8% of the total energy and the wind turbines are producing 42.2% of the total energy as it is shown in Table 5.2.

Table 5.2 The electrical power production for the second system

Production	kWh/year	Percentage %
Solar panel	1,309,947	57.8
Wind turbine	956,227	42.2
Diesel generator	-	-
Total	2,266,173	100

For the first hybrid system which is PV / wind / diesel hybrid system and in terms of the average power produced by the solar panels, wind turbines and diesel generator, Table 5.3 is illustrating the values in kW.

Table 5.3 Power output monthly average for the first system (kW)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Solar	141	166	209	203	227	240	254	248	241	195	150	116
Wind	42	39	25	19	14	14	23	30	25	26	32	39
Diesel	25	14	16	9	9	7	1	5	9	11	27	33

For the second hybrid system which is PV / wind hybrid system, the averages of the power production for the solar panels and wind turbines are illustrating in Table 5.4.

Table 5.4 Power output monthly average for the second system (kW)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Solar	106	124	157	152	170	180	190	186	181	146	112	87
Wind	166	158	100	78	56	54	93	120	100	104	127	155

The monthly average electric production for the first hybrid system is presented in Figure 5.5, and for the second hybrid system, Figure 5.6 illustrates it.

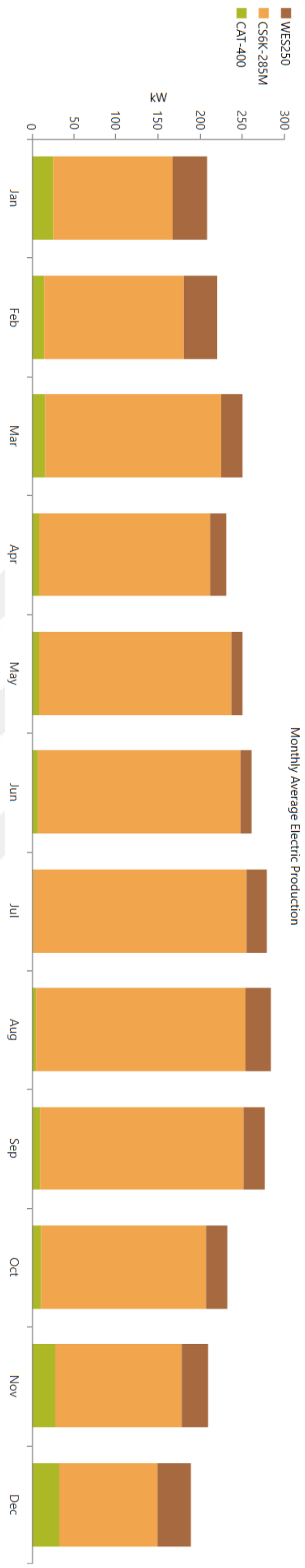


Figure 5.5 Monthly average electric production for the first system

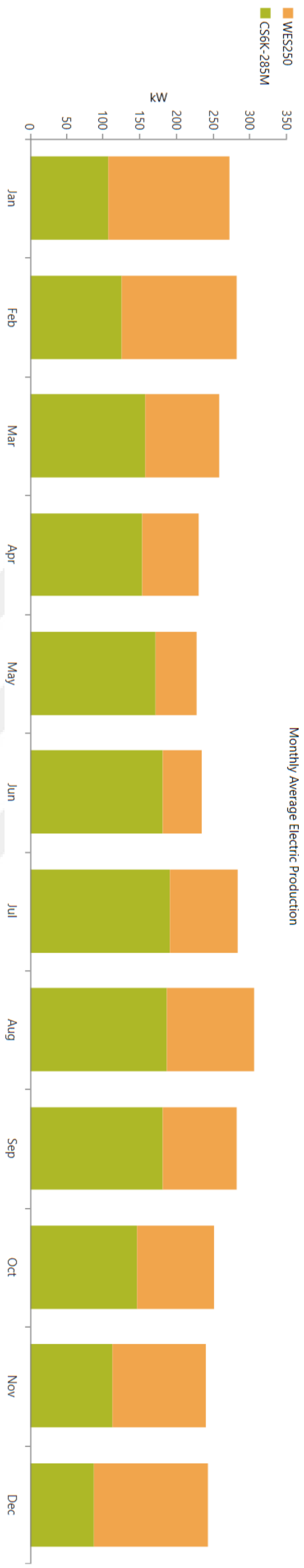


Figure 5.6 Monthly average electric production for the second system

For the PV system in the first hybrid system, the yearly PV power output is shown in Figure 5.7. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

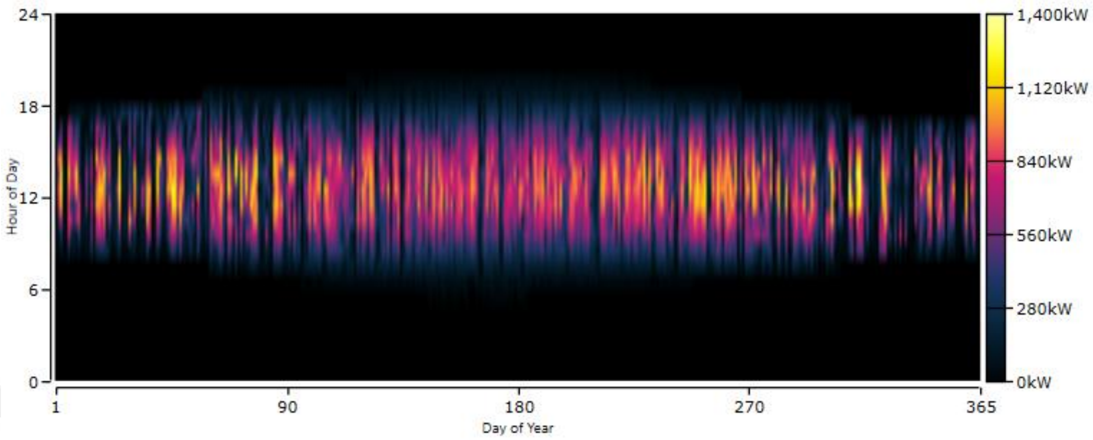


Figure 5.7 PV power output for a year in the first hybrid system

For the wind turbine system in the first hybrid system, the yearly wind turbine power output is shown in Figure 5.8. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

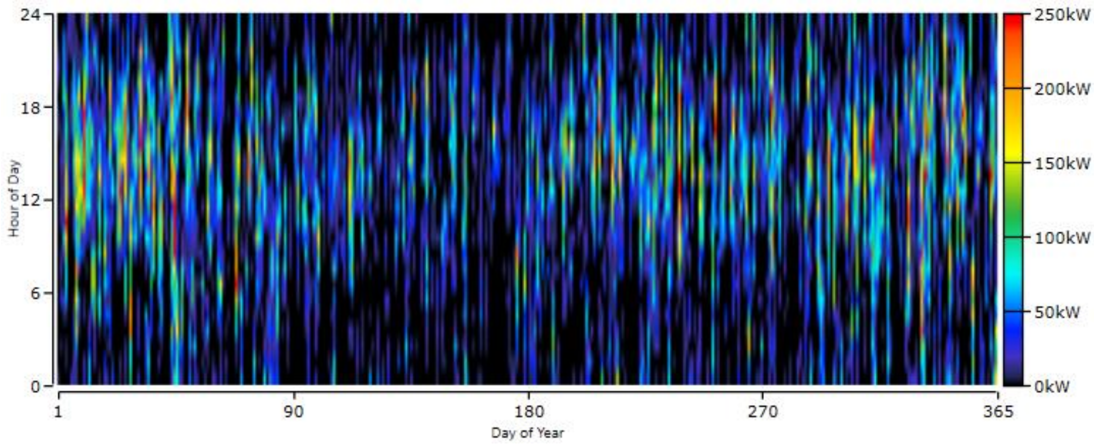


Figure 5.8 Wind turbine power output for a year in the first hybrid system

In the second hybrid system, the yearly PV power output is shown in Figure 5.9. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

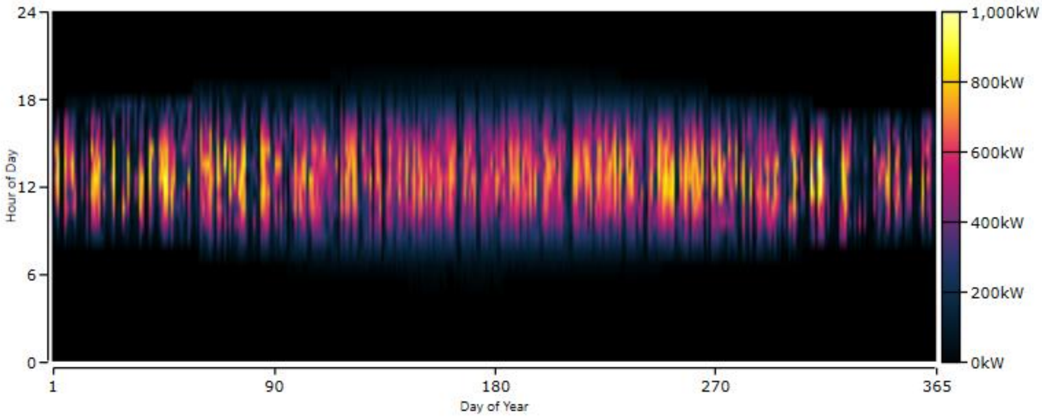


Figure 5.9 PV power output for a year in the second hybrid system

In the second hybrid system, the yearly wind turbine power output is shown in Figure 5.10. The energy production is colored according to the hours and days of the year.

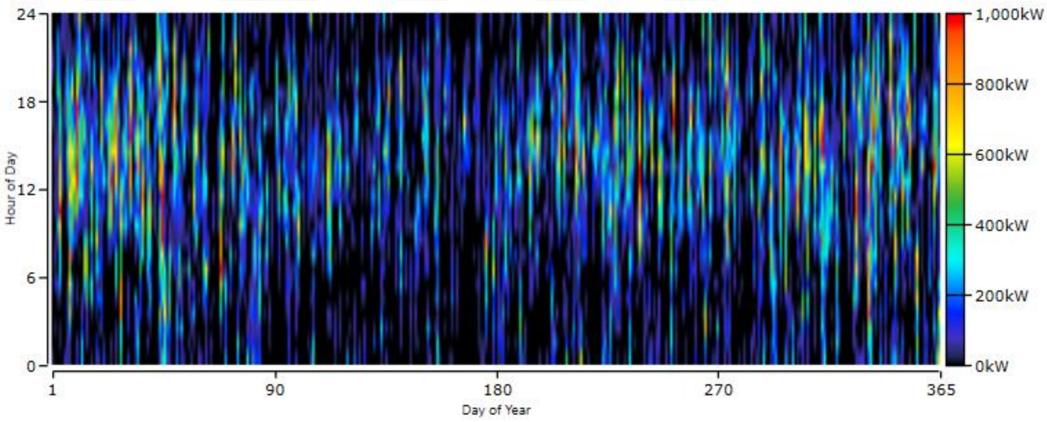
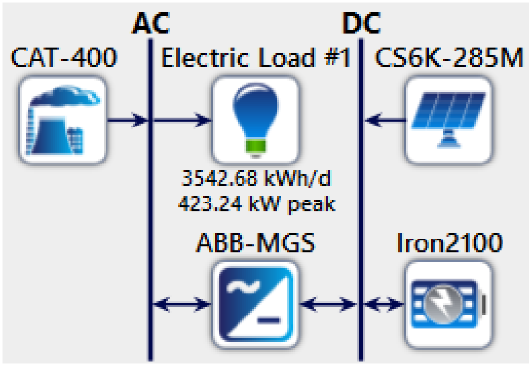


Figure 5.10 Wind turbine power output for a year in the second hybrid system

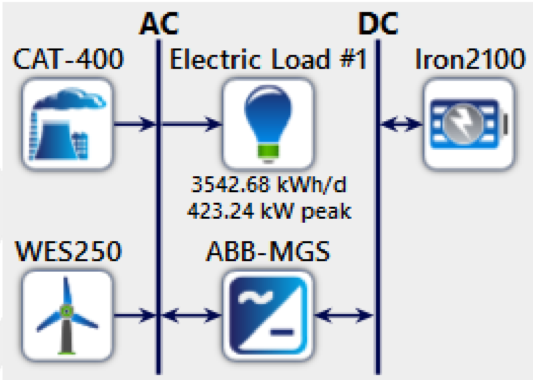
5.1.3 The Case Of Urla / Izmir

5.1.3.1 The Simulations Of The Systems

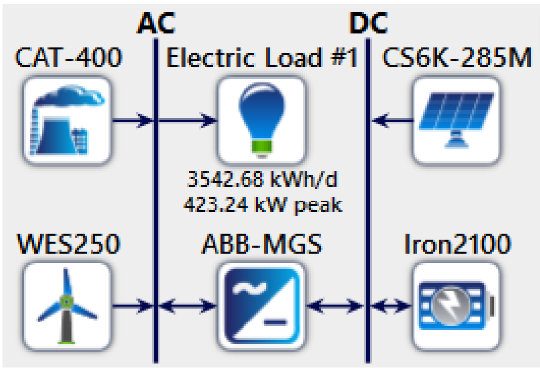
The same previous studies with the same load were applied for Urla / Izmir with the same systems which are the hybrid PV / diesel energy system which is shown in Figure 5.11 (a), the hybrid wind / diesel energy system which is shown in Figure 5.11 (b) and the hybrid PV / wind / diesel energy system which is shown in Figure 5.11 (c). The values of the solar panels, wind turbines, batteries and the converter are the same with the previous studies.



(a)



(b)



(c)

Figure 5.11 The schematic figures of the proposed hybrid systems
(a) PV / diesel – (b) Wind / diesel – (c) PV / wind / diesel

5.1.3.2 The Optimization Results

After the simulation processes were done for all of the possible solutions for the proposed hybrid systems, HOMER shows the results in a list according to their cost of energy (COE), initial capital cost and net present cost (NPC).

The categorized optimization results which HOMER offered are illustrated in Figure 5.12 for three hybrid systems.

- In the first system which is hybrid PV / diesel system that is shown in Figure 5.12 (a), the renewable fraction is 89.6%.
- In the second hybrid wind / diesel system which is illustrated in Figure 5.12 (b), the renewable fraction is 74.7%.
- For the third hybrid PV / wind / diesel system which is presented in Figure 5.12 (c), HOMER is suggesting two systems, a system by using the diesel generator and another system which is not using the diesel generator.

For the hybrid PV / wind / diesel system, It is obvious that the best system is the first one because it has the lowest cost of energy (COE) and net present cost (NPC), but on the other hand, the first system is using the renewable resources with a percentage of 94.7% which is the renewable fraction, unlike the second system which is using 100% of the renewable resources, but it is more expensive in comparison with the first system.

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System
CS6K-285M (kW)	CAT-400 (kW)	Iron2100	ABB-MGS (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
1,100	320	31	300	LF	$0.141	$2.36M	$77,796	$1.35M	89.6

(a)

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System
WES250	CAT-400 (kW)	Iron2100	ABB-MGS (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
4	320	25	360	LF	$0.224	$3.74M	$153,302	$1.75M	74.7

(b)

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture						Cost				System
CS6K-285M (kW)	WES250	CAT-400 (kW)	Iron2100	ABB-MGS (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
800	1	320	29	300	LF	$0.131	$2.18M	$58,980	$1.42M	94.7
1,300	3		60	360	CC	$0.206	$3.45M	$51,564	$2.78M	100

(c)

Figure 5.12 The categorized optimization results of HOMER for the proposed hybrid systems (a) PV / diesel – (b) Wind / diesel – (c) PV / wind / diesel

From the previous Figure 5.12, the cost of energy (COE) and the initial capital cost for the three systems can be noticed.

- For the first case in Figure 5.12 (a), the hybrid PV / diesel system contains 1,100 kW solar panels, one generator with 320 kW and 31 battery. The cost of energy (COE) is equal to 0.141 US dollar for 1 kW and the initial capital cost is 1.35 million dollar.
- The second case which is illustrated in Figure 5.12 (b), the hybrid wind / diesel system is composed of four wind turbines, one generator with 320 kW and 25 battery. The cost of energy (COE) is equal to 0.224 US dollar for 1 kW and the initial capital cost is 1.75 million dollar.
- The third system which is the hybrid PV / wind / diesel system, is divided into two suggestions from HOMER software.
  The first proposed system consists of 800 kW solar panels, one wind turbines, one generator with 320 kW and 29 battery. It has the lowest cost of energy (COE) which is equal to 0.131 US dollar for 1 kW and the system’s initial capital cost is 1,42 million dollar. It can be noticed that the renewable fraction in this case is equal to 94.7%.
  On the other hand and for the second proposed system, the system consists of 1,300 kW solar panels, 3 wind turbines and 60 battery. This system is a little bit more expensive than the first system in the terms of using more solar panels, wind turbines and batteries, the cost of energy (COE) in this case is 0.206 US dollar for 1 kW and the system’s initial capital cost is 2.78 million dollar. On the other hand, the diesel generator is not being used which makes the system

depending on the renewable resources 100% and for that reason, the renewable fraction here is 100%.

The previous results are expressing that the third system which is the hybrid PV / wind / diesel system has the lowest cost of energy (COE) among the three systems, and for that reason, it is the best system to be chosen.

5.1.3.3 The Optimization Results For The Hybrid PV / Wind / Diesel System

The results of the simulation for the hybrid PV / wind / diesel system, which HOMER software suggested two types of it, are listed in Table 5.5 and Table 5.6 respectively with the electrical power generated from the components in each system per year and their percentage.

The first hybrid system is producing a yearly electric energy with an approximate value of 1,862 GWh, the PV system is producing 74.5% of the total energy, the wind turbines are producing 21.7% of the total energy and the diesel generator is producing 3.72% of the total energy as it is shown in Table 5.5.

Table 5.5 The electrical power production for the first system

Production	kWh/year	Percentage %
Solar panel	1,384,657	74.5
Wind turbine	403,632	21.7
Diesel generator	61,103	3.72
Total	1,857,392	100

In the second system, HOMER proposed the system without the use of the diesel generator, in that case, the energy production from the second system is 100% clean energy because it is producing from the renewable resources without the need of the diesel generator. The total energy in this system is approximately of 3,461 GWh, the PV system is producing 65% of the total energy and the wind turbines are producing 35% of the total energy as it is shown in Table 5.6.

Table 5.6 The electrical power production for the second system

Production	kWh/year	Percentage %
Solar panel	2,250,068	65.0
Wind turbine	1,210,896	35.0
Diesel generator	-	-
Total	3,460,964	100

The average power produced by the solar panels, wind turbines and diesel generator for the first hybrid system which is PV / wind / diesel hybrid system is shown in Table 5.7 and the values in kW.

Table 5.7 Power output monthly average for the first system (kW)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Solar	109	130	159	172	185	193	194	193	187	160	121	92
Wind	56	78	61	42	27	25	38	34	32	58	49	55
Diesel	20	5	5	2	2	2	1	3	4	4	20	26

Table 5.8 is showing the averages values for the second hybrid system which is PV / wind hybrid system, the averages of the power production for the solar panels and wind turbines are in kW.

Table 5.8 Power output monthly average for the second system (kW)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Solar	177	212	259	280	300	313	315	314	304	260	196	150
Wind	168	235	183	127	80	75	114	102	95	175	147	164

The monthly average electric production for the first hybrid system is presented in Figure 5.13, and for the second hybrid system, Figure 5.14 illustrates it.

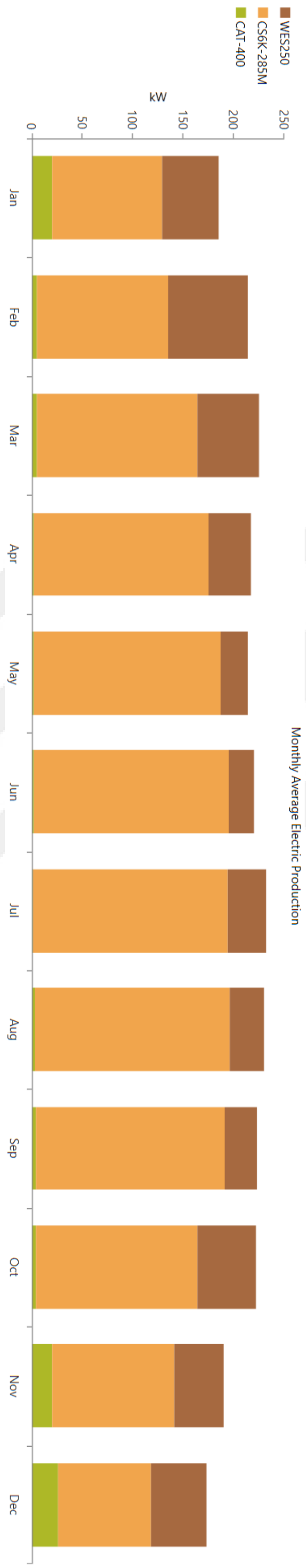


Figure 5.13 Monthly average electric production for the first system

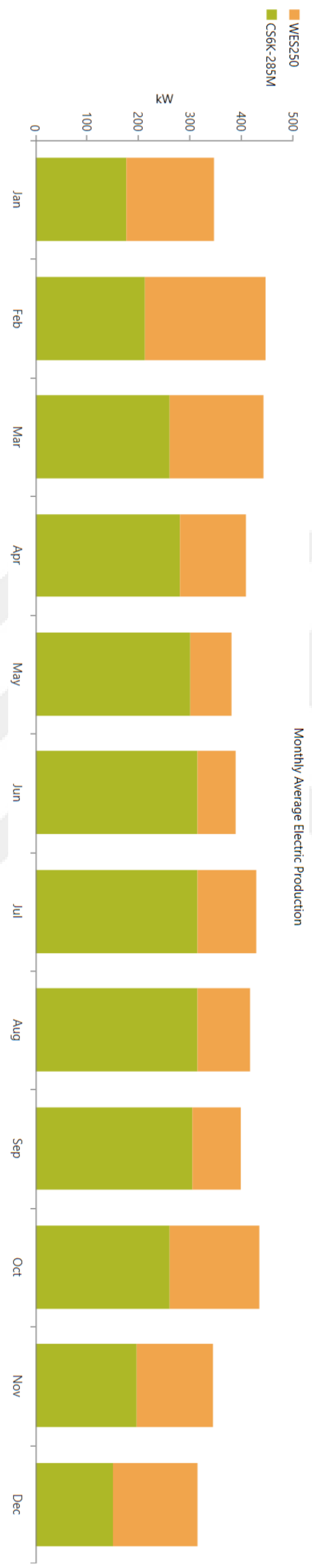


Figure 5.14 Monthly average electric production for the second system

For the PV system in the first hybrid system, the yearly PV power output is shown in Figure 5.15. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

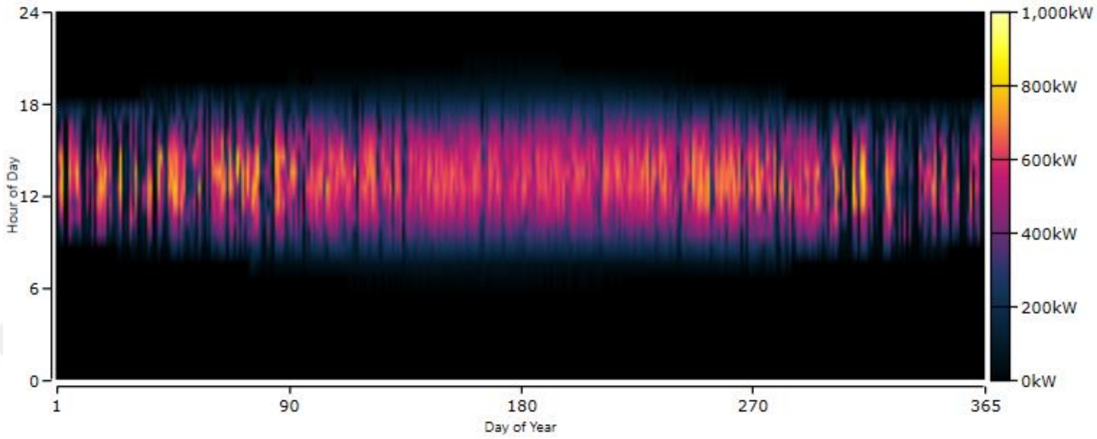


Figure 5.15 PV power output for a year in the first hybrid system

For the wind turbine system in the first hybrid system, the yearly wind turbine power output is shown in Figure 5.16. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

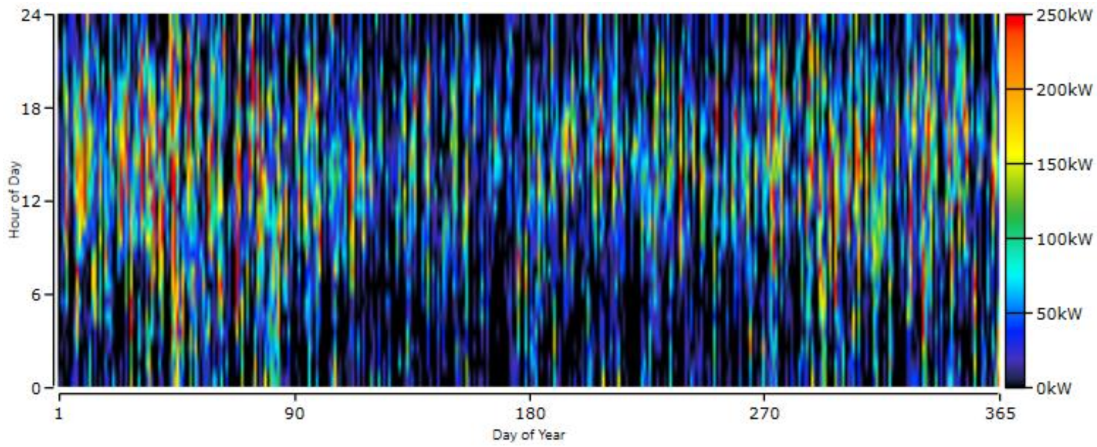


Figure 5.16 Wind turbine power output for a year in the first hybrid system

In the second hybrid system, the yearly PV power output is shown in Figure 5.17. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

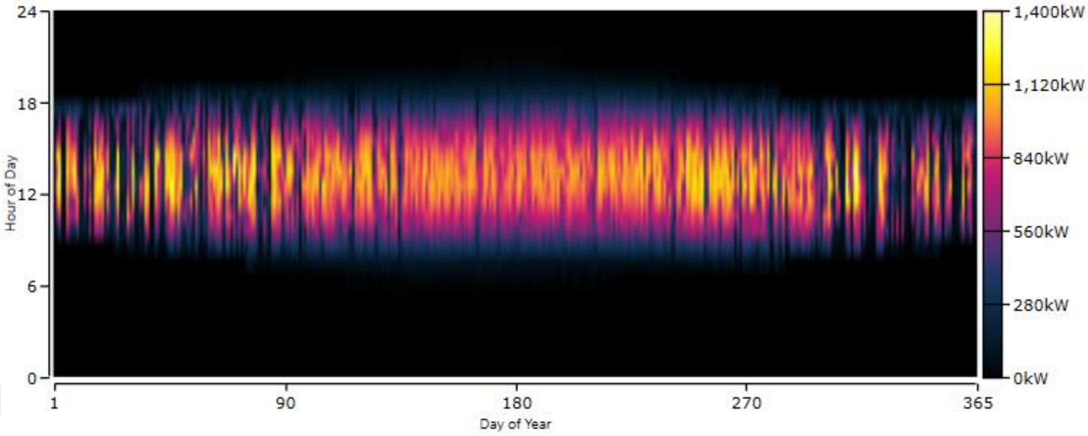


Figure 5.17 PV power output for a year in the second hybrid system

In the second hybrid system, the yearly wind turbine power output is shown in Figure 5.18. The energy production is illustrated in the figure by the colors according to the day of the year and the hour of the day.

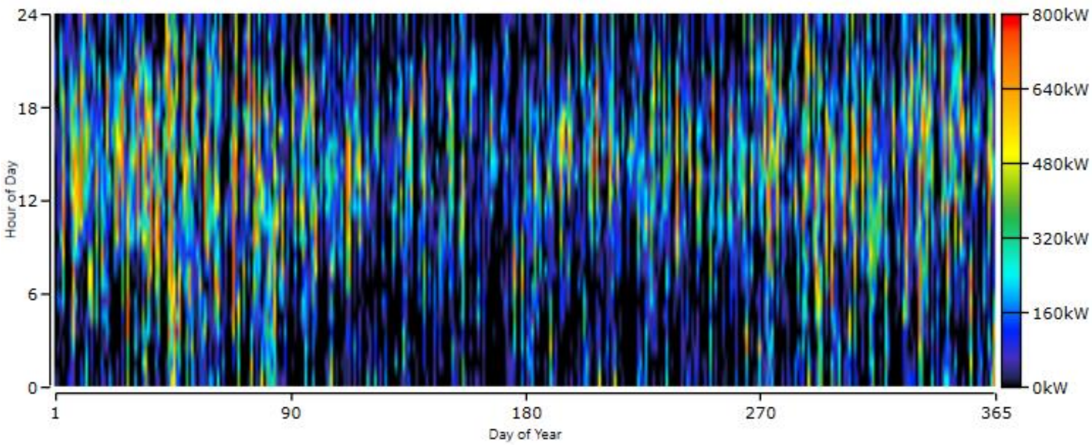


Figure 5.18 Wind turbine power output for a year in the second hybrid system

5.2 The Financial Evaluation

5.2.1 The Case Of Cubuk / Ankara

5.2.1.1 The First Hybrid System

HOMER can provide a cost summary report for the user with the details of the components which were being used in the simulation, Figure 5.19 shows the capital, operating, replacement and some other costs for the first hybrid system with a specific color for each component which was being used during the simulation.

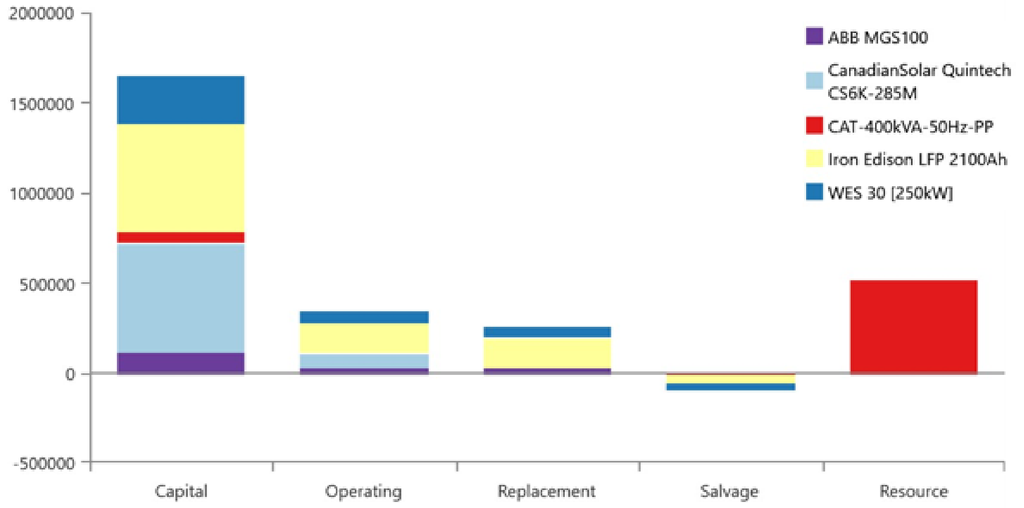


Figure 5.19 The cost summary for the first hybrid system according to the components

The capital and operating costs for the components are illustrated in Table 5.9.

Table 5.9 The capital and operating costs for the components in the first hybrid system

Name	Capital	Operating
CanadianSolar Quintech CS6K-285M	$600,000	$77,565
WES 30 [250kW]	$262,500	$67,869
CAT-400kVA-50Hz-PP	$60,000	$6,813
ABB MGS100	$120,000	$31,026
Iron Edison LFP 2100Ah	$600,000	$155,163
System	$1.64M	$338,437

5.2.1.2 The Second Hybrid System

In Figure 5.20, the capital, operating, replacement and some other costs for the second hybrid system with a specific color for each component which was being used during the simulation are being illustrated.

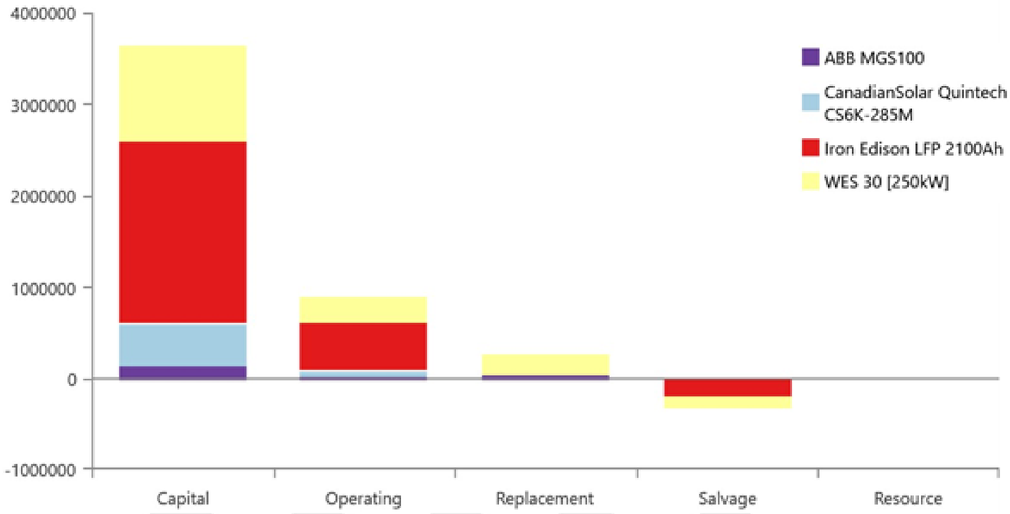


Figure 5.20 The cost summary for the second hybrid system according to the components

The capital and operating costs for the components which were being used are illustrated in Table 5.10.

Table 5.10 The capital and operating costs for the components in the second hybrid system

Name	Capital	Operating
CanadianSolar Quintech CS6K-285M	$450,000	$58,174
WES 30 [250kW]	$1.05M	$271,478
ABB MGS100	$144,000	$37,231
Iron Edison LFP 2100Ah	$2.00M	$517,134
System	$3.64M	$884,017

5.2.2 The Case Of Urla / Izmir

5.2.2.1 The First Hybrid System

The cost summary report for the hybrid system in Urla / Izmir is detailed in Figure 5.21.

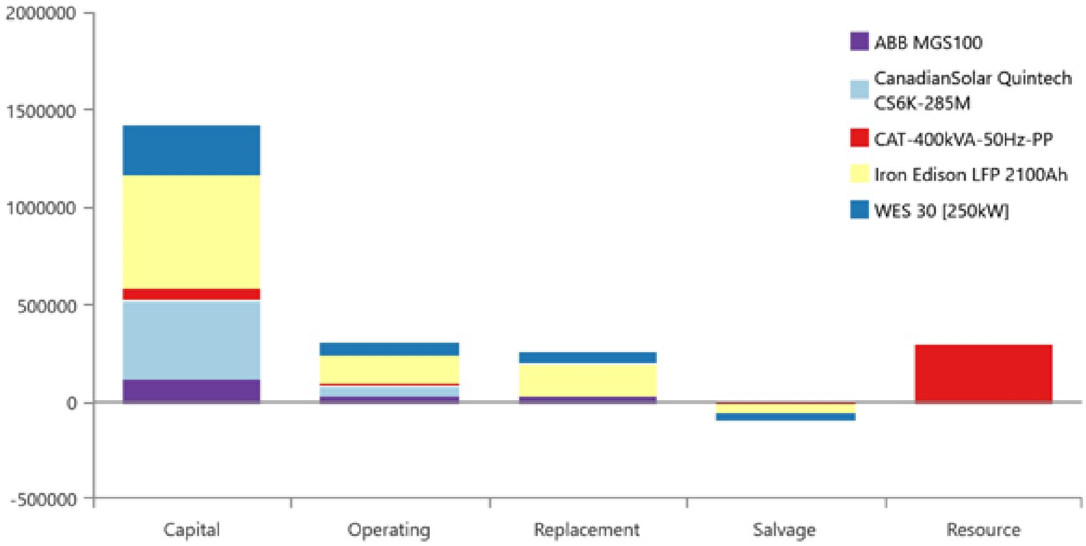


Figure 5.21 The cost summary for the first hybrid system according to the components

The capital and operating costs for the components which were being used are illustrated in Table 5.11.

Table 5.11 The capital and operating costs for the components in the first hybrid system

Name	Capital	Operating
CanadianSolar Quintech CS6K-285M	$400,000	$51,710
WES 30 [250kW]	$262,500	$67,869
CAT-400kVA-50Hz-PP	$60,000	$4,150
ABB MGS100	$120,000	$31,026
Iron Edison LFP 2100Ah	$580,000	$149,992
System	$1.42M	$304,748

5.2.2.2 The Second Hybrid System

The same cost summary report for the second system is illustrated In Figure 5.22.

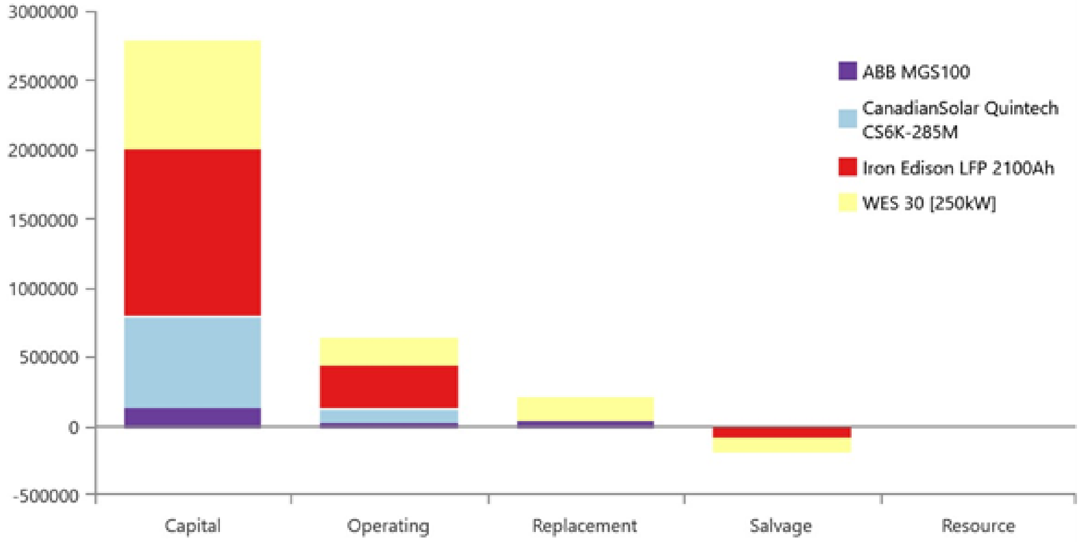


Figure 5.22 The cost summary for the second hybrid system according to the components

The capital and operating costs for the components which were being used are illustrated in Table 5.12.

Table 5.12 The capital and operating costs for the components in the second hybrid system

Name	Capital	Operating
CanadianSolar Quintech CS6K-285M	$650,000	$84,029
WES 30 [250kW]	$787,500	$203,608
ABB MGS100	$144,000	$37,231
Iron Edison LFP 2100Ah	$1.20M	$310,293
System	$2.78M	$635,162

5.3 The Environmental Impact

5.3.1 The Case Of Cubuk / Ankara

It is obvious that the use of the renewable energy resources besides the conventional sources has a deep and positive effect on the environment by reducing the emissions of the harmful gases. By using the PV systems and wind turbines, the emissions will be much less than before as the renewable resources are producing energy without producing harmful emissions.

HOMER shows the yearly production for every pollutant in the power system by the unit of kg/yr. The pollutants like carbon dioxide, sulfur dioxide and other emissions.

The first hybrid system which has the diesel generator, the emissions are being showed in the next Table 5.13.

Table 5.13 The emissions of the first hybrid system

Quantity	Value	Units
Carbon Dioxide	92,645	kg/yr
Carbon Monoxide	140	kg/yr
Unburned Hydrocarbons	1.05	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	230	kg/yr
Nitrogen Oxides	508	kg/yr

On the other hand, and for the second hybrid system which is not using the diesel generator, the emissions are equal to zero which means that the system is producing a 100% clean energy and it is environmentally friendly as shown in Figure 5.23.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Figure 5.23 The emissions for the second hybrid system

5.3.2 The Case Of Urla / Izmir

The same study of Cubuk / Ankara is repeated in the terms of the environmental impact for the hybrid system in Urla / Izmir.

The first hybrid system which has the diesel generator, the emissions are being showed in the next Table 5.14.

Table 5.14 The emissions of the first hybrid system

Quantity	Value	Units
Carbon Dioxide	53,482	kg/yr
Carbon Monoxide	80.8	kg/yr
Unburned Hydrocarbons	0.608	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	133	kg/yr
Nitrogen Oxides	293	kg/yr

As mentioned before, in the case of Cubuk / Ankara, and for the second hybrid system which will be in Urla / Izmir, the emissions are equal to zero which means that the system is producing a 100% clean energy and it is environmentally friendly as shown in Figure 5.24.

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Figure 5.24 The emissions for the second hybrid system

CHAPTER 6

CONCLUSION AND SUGGESTIONS

6.1 Conclusion

In this thesis, a study was proposed about the hybrid PV / wind energy system which took a place in Turkey. The study was done by using the trial version of the famous Hybrid Optimization Model for Electrical Renewable (HOMER) software. According to the geographical location of two areas in Turkey which are Cubuk / Ankara and Urla / Izmir, it found that the solar radiation and wind speed possibilities in Urla / Izmir are higher than Cubuk / Ankara and for that reason, Urla / Izmir is better to perform the proposed hybrid PV / wind energy system. The solar radiation and wind speed values were recieved from NASA surface meteorology and solar energy database for the selected location according to its longitude and latitude. After making the simulation, HOMER suggested two hybrid PV / wind systems to perform in the selected areas, the first hybrid system consists of PV modules, wind turbines, batteries, converter and diesel generator. The second hybrid system consists of PV modules, wind turbines, batteries and converter. For the first system, and by considering the usage of the diesel generator, it is obvious that the hybrid system is not producing a 100% clean energy, on the other hand, the second hybrid system is producing a 100% clean energy because it does not use the diesel generator at all. But in other words, and according to the results which were discussed in chapter 5, the first hybrid system which is using the diesel generator, it is found that it is cheaper in the terms of the cost of energy (COE) and the initial capital cost than the second hybrid system which is producing a clean energy depending on the renewable resources with the percentage of 100% as it is not using the diesel generator. In the terms of the environmental impact, the second hybrid system has the advantage of producing the energy in a friendly way with the environment because the harmful emissions are zero unlike the first hybrid system which is using the diesel generator and as a result, the harmful emissions will be produced like the carbon dioxide and other types of harmful emissions.

6.2 Suggestions

The study took into consideration only two areas in Turkey which are located in Ankara and Izmir, for that, it would be great to compare the results with other cities in Turkey by paying attention to the other factors like the temperature and the components' efficiency and some other factors. In addition, the study could also be done by measuring the real values of the solar radiation and the wind speed in a specific location and compare the results with the data which were received from the NASA surface meteorology and solar energy database tool which HOMER software is offering to use. Also, it should take into account the expanding of the hybrid system to be able to cover the electrical consumption in case of the growing of the electrical load.

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TOPICS OF INTEREST

- Hybrid Systems
- Solar and Wind Energy
- Renewable Energy
- On-grid and Off-grid Systems