ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

ANALYSIS OF HYBRID WIND-SOLAR POWER PLANT FOR ITU AYAZAGA CAMPUS

M.Sc. THESIS

Nima JAFARZADEH

Energy Science and Technology Division

Energy Science and Technology Programme

JUNE 2017

ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

ANALYSIS OF HYBRID WIND-SOLAR POWER PLANT FOR ITU AYAZAGA CAMPUS

M.Sc. THESIS

Nima JAFARZADEH
(301131049)

Energy Science and Technology Division

Energy Science and Technology Programme

Thesis Advisor: Assist. Prof. Dr. Burak BARUTÇU

JUNE 2017

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

İTÜ AYAZAĞA YERLEŞKESİ İÇİN RÜZGAR/GÜNEŞ HİBRİT GÜÇ SANTRALI ANALİZİ

YÜKSEK LİSANS TEZİ

Nima JAFARZADEH
(301131049)

Enerji Bilim ve Teknoloji Anabilim Dalı

Enerji Bilim ve Teknoloji Programı

Tez Danışmanı: Yrd. Doç. Dr. Burak BARUTÇU

HAZİRAN 2017

Nima JAFARZADEH, a M.Sc. student of ITU Energy Institute student ID 301131049, successfully defended the thesis entitled "ANALYSIS OF HYBRID WIND-SOLAR POWER PLANT FOR ITU AYAZAGA CAMPUS", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assist. Prof. Dr. Burak BARUTÇU** ....
İstanbul Technical University

Jury Members : **Prof. Dr. Önder GÜLER** ....
İstanbul Technical University

Assoc. Prof. Dr. Ozan ERDİNÇ ....
Yıldız Technical University

Date of Submission : 5 May 2017
Date of Defense : 6 June 2017

To my family,

FOREWORD

I would like to express my deep appreciation and thanks for my advisor, Dr. Burak Barutcu This was impossible without his warm guidance, support and encouragement during the entire master study.

I would like to thank my sister Sevda Jafarzadeh for his kind and effective helps and guidence. At the end, I would like to thanks my family for their warm support and love in my life.

June 2017

Nima JAFARZADEH
(Electrical Engineer)

TABLE OF CONTENTS

Page

ABBREVIATIONS

AC **:** Alternating Current
DC **:** Direct Current
HAWT **:** Horizontal Axis Wind Turbine
ITU **:** Istanbul Technical University
PV **:** Photovoltaic
VAWT **:** Vertical Axis Wind Turbine

LIST OF TABLES

LIST OF FIGURES

Page

ANALYSIS OF HYBRID WIND-SOLAR POWER PLANT FOR ITU AYAZAGA CAMPUS

SUMMARY

Nowadays most of the industrial countries are trying to find alternatives to fossil fuels because of several reasons. It seems that renewable energy can be a true choice for replacing the fossil fuels in these countries. This replacement is justifiable from two aspects. At first, it can be described from the financial side. Various fluctuations in fossil fuels prices during last decade have made the producer to find an energy with certain prices. By choosing renewable energy this problem can be solved because in this by establishing your own power generation system, you will not need to an external energy source to buy. This kind of energies just initial investment for establishment after that will operate at very low cost. Furthermore, renewable energy can provide various job opportunities in various fields directly and indirectly. Decreasing the cost of renewable energy equipment in recent years is another reason for choosing this kind of energy.

Moreover, fossil fuels can cause different environmental problems. After the industrial revolution, the greenhouse gasses emission increased dramatically under this condition we can see climate change in the world. Also, fossil fuels cause air and water pollution and it linked to different breathing problems, chronic diseases and types of cancers. However, renewable energies are environmentally friendly, and air pollution is zero in this case also there is no greenhouse gasses emission. According to these reasons which are mentioned above the renewable energies are going to be future of power generation for a sustainable and clean world.

In this thesis, we consider a hybrid wind/solar power plant which is located in ITU Ayazaga Campus. The main purpose of choosing this type of hybrid system is to show the complementary feature of solar and wind energy. It is obvious that a solar energy system reaches to its peak generation in summer. On the other hand, the maximum generation of a wind energy system occurs in winter because of the strong wind at this season. By adding the generation of these two systems, we can see the output power of a hybrid system is more consistent than stand alone.

At first, we have collected the weather data from a meteorology station which was located in ITU. These data belong to a one-year duration which had started at 00:00 in 1st January 2003 and ends at 23:59 on 31 December 2003.

These data consist hourly average of solar irradiances, temperature and, wind speed at 2 meters and 10meters heights. For calculating the amount of solar irradiance reaching the PV panels, we have calculated the incidence angle hourly. According to the incidence angle equation, we have calculated declination of the sun in every hour and hour angle by considering panel tilt angle 31 degrees. After that, we have obtained the panel temperature from the equation which estimates the photovoltaic modules operating temperature by using simple correlation. The temperature of panels was used

for obtaining the efficiency of the panels which is depended to temperature. This calculation is done for three type of PV panels:

- Monocrystalline
- Polycrystalline
- Multijunction

In the next step by considering the nominal output power 900 kW the number of the panels is computed. Also, the total panel area is obtained for each type. By multiplying this area to solar irradiances and panel efficiency, the annual solar power generation is calculated.

In wind power generation we have chosen Enercon E-44 wind turbine which has 900 kW nominal output power and 45meters height. For computing wind speed the Hellman equation is used in a way that the Hellman exponent is obtained by using the wind speed at given heights. Then it is calculated in 45 meter which is the height of the turbine's hub. We have driven an equation according to the curve of the wind speed and output power characteristic. Finally, we have used the calculated wind speed at 45 meters as an input of this equation so we can extract the generation of the wind system during a year.

At the last step, we have computed the daily energy generation of each system. By adding solar and wind system outputs we obtained the total energy generation of the hybrid system for each day, then we have computed the solar system proportion and wind system proportion in percent for each day. By calculating the daily average proportion of wind system and solar system and multiplying annual average of these percent to the output power of each system the optimal power generation capacity is obtained and the nominal established is 900 kW.

İTÜ AYAZAĞA YERLEŞKESİ İÇİN RÜZGAR/GÜNEŞ HİBRİT GÜÇ SANTRALI ANALİZİ

ÖZET

Günümüzde gelişmiş ülkelerin çoğu fosil yakıtlar yerine geçebilecek alternatif enerji kaynakları bulmaya çalışmaktadır. Yenilenebilir enerji kaynakları da bu alternatifler içinde önemli bir yer tutmaktadır. Bu arayışa iki temel gerekçe gösterilebilir. Birincisi olayın finansal yönüyle ilgilidir. Son yıllarda fosil yakıt fiyatlarında sık görülen değişimler üreticileri fiyatı stabil enerji kaynakları aramaya yöneltmiştir. Yenilenebilir enerji kaynakları bu anlamda probleme bir çözüm getirmektedir. Rüzgar, güneş gibi yenilenebilir enerji kaynaklarından enerji üreten sistemler kurulduğu takdirde yakıt maliyeti ortadan kalkacaktır. Bu tür sistemler ilk kurulum maliyeti dışında düşük bakım maliyetleriyle 20 – 25 yıl işletilebilmektedir. Ayrıca yenilenebilir enerji santrallarının artması çeşitli alanlarda yeni iş imkanları doğuracağından istihdamı arttıracaktır. Bu avantajlarının yanında yenilenebilir enerji santrallarının maliyetlerinde son yıllarda görülen düşüş de bu yönde tercih yapmaya yönelten bir diğer sebeptir.

İkinci olarak çevre açısından ele alındığında, fosil yakıt kullanımın çevre üzerindeki olumsuz etkileri yine işletimleri sırasında çevreye zararlı emisyon yapmayan rüzgar, güneş gibi yenilenebilir enerji kaynaklarına yönelmek için bir diğer sebeptir. Sanayi devriminden sonra sera gazlarında görülen dramatik artış ve bunun sonucu olan iklim değişimi günümüzde ciddiyeti giderek artan bir problem oluşturmaktadır. Bunun dışında fosil yakıtların emsiyonları hava ve su kirliliğine sebep olmakta, solunum problemleri, kronik hastalıklar ve bazı kanser türlerine yakalanma riskini arttırmaktadır. Buna karşın yenilenebilir enerji kaynakları işletimleri sırasında çevreye zararlı emisyon yapmayan dolayısıyla havayı ve suyu kirletmeyen, sera etkisini arttırmayan çevre dostu sistemler olarak karşımıza çıkmaktadırlar. Yukarıda bahsedilen sebepler nedeniyle, yenilenebilir enerji kaynakları, temiz ve sürdürülebilir bir dünya için, temiz enerji üretimine giden yolda en avantajlı metotlar arasında yer almaktadır.

Rüzgar enerjisi zararlı gaz salınımı yapmaz ve bundan dolayı atmosfere zararı yoktur. Yenilenebilir bir enerji kaynağı olan rüzgar enerjisi, su kirliliği de yaratmaz. Rüzgar santralleri herhangi bir atığa yol açmaz, bu nedenle atık olarak olumsuz etkileri söz konusu değildir. Aşırı büyük oldukları için görüntü kirliliğine neden olurlar, ayrıca gürültülü çalıştıkları için ses kirliliği de oluştururlar. Rüzgar türbinlerinin neden olduğu hava akımı, göç eden kuşları kendine çeker. Bu akımdan kurtulamayan kuşlar türbinlere çarparak ölürler.

Güneş enerjisi, atmosfere herhangi bir zararlı gaz salmaz, ancak kurulum aşamasında azımsanacak kadar az bir zararı mevcuttur. Akü destekli olan güneş enerji sistemlerinde, akü içerisinde bulunan sıvının suya karışma ihtimali vardır. Güneş

enerjisinin kurulumu yapılırken ambalaj atıkları bulunur, bunun dışında herhangi bir atık söz konusu değildir.

Yenilenebilir enerjiler, sağlamış olduğu faydalar nedeni ile oldukça önemlidir. Yenilenebilir enerji teknolojileri çevreyi, fosil enerji teknolojilerinden daha az etkiliyor. Bir kirleticisinin olmaması, kaynağının bitmemesi ve her zaman var olacak olması nedeni ile çevresel olarak oldukça faydalıdır. Ayrıca diğer sonlu ve sınırlı olan enerji kaynakları ile kıyaslandığı zaman hiç tükenmiyor olmaları, gelecek nesillerin de kullanımı için oldukça faydalıdır. Yüksek maliyetli enerji dışı alımlarının yerine, tesislerin kurulması adına malzeme ve insan gücüne yönelik yapılan yenilenebilir enerji yatırımları, yapıldığı yörede kalıyor olup, iş ve ekonomi için de enerji kaynağı oluyor.

Gelecek kuşakların enerji gereksinimlerini karşılamak ve çevreye verilen hasarı en aza düşürebilmek için yenilenebilir ya da sürdürülebilir enerji kaynaklarına yönelmek gerekiyor. Yenilenebilir enerji kaynakları, herhangi bir risk olmadan gerekli enerji ihtiyacını karşılamak adına üretilen enerji anlamına gelir.

Bu tez çalışmasında İTÜ Ayazağa kampüsünde kurulabilecek bir rüzgar/güneş hibrit enerji santralının optimizasyonu ve yıl içinde bu santraldan elde edilebilecek elektrik enerjisinin hesabı ele alınmıştır. Gelecekte enerji üretiminde büyük öneme sahip olacakları öngörüldüğü ve Türkiye'de anlamlı potansiyellere sahip oldukları için hibrit santral bileşenleri olarak rüzgar ve güneş enerjisi seçilmiştir. Bu iki enerji kaynağına dayanan bir hibrit sistem kurulumunun ele alınmasındaki bir diğer sebep de güneşin potansiyelinin yazın ve rüzgarın potansiyelinin de kışın yüksek olmasıdır. Bu sayede planlanan hibrit santralın yıl içindeki enerji üretimi, tek başına rüzgar veya güneş santralı kullanılması durumuna göre daha homojen olacaktır.

Lisanssız üretim sınırları içinde kalması için santralın toplam kurulu gücü 900 kW ile sınırlandırılmıştır. 900 kW kurulu güç sınırı dahilinde kalarak yılın her günü için rüzgar ve güneşten elde edilebilecek elektrik enerjileri hesaplanarak bütün yıl için üretilen enerjiyi maksimize edecek rüzgar-güneş kurulu güç oranı bulumuştur. Elde edilen sonuçlara göre en yüksek enerji üretimi yapacak sistemin kapasite fatörü bulunmuştur. İTÜ Ayazağa kampüsü için rüzgar şartlarının iyi olmadığı görülmüştür.

Yapılan çalışmada, İTÜ Ayazağa yerleşkesinde bulunan meteoroloji istasyonunun 2003 yılına ait verleri kullanılmıştır. Çalışmada kullanılan veriler, saatlik ortlamalar olarak kaydedilmiş; global ışınım, sıcaklık, 2 ve 10 m yüksekliklerde alınmış rüzgar hızı verileridir. Panel yüzeyine gelen ışınım şiddetlerinin hesaplanması için, yılın günü ve saate göre güneşin konumu hesaplanarak, global ışınım değerleri üzerinde açı düzeltmeleri yapılmıştır. İstanbul için optimal sabit panel açısı olarak 31^o derece seçilmiştir. Panellerin azimut açıları 0^o Güney azimutu olarak seçilmiştir. Panel sıcaklığı verim üzerinde önemli etkiye sahip olduğu için hava sıcaklığı ve ışınım verilerinden panel sıcaklıkları hesaplanarak verim düzeltmeleri yapılmıştır. Enerji üretim hesapları aşağıda verilen 3 panel türü üzerinde ayrı ayrı yapılmıştır:

- Mono-kristal
- Poli-kristal
- Multi-junction

Bütün hesaplar 900 kW kurulu güçte PV dizileri üzerinde yapılmıştır. Bunun için her panel tipi için 900 kW kurulu gücü sağlayacak panel sayısı hesaplanarak toplam panel alanları da belirlenmiştir.

Rüzgar enerjisi hesapları için yine 900 kW kurulu güce sahip, 3 kanatlı, rotor çapı 44 m ve hub yüksekliği 45 m olan Enercon E-44 rüzgar türbini seçilmiştir. 45 m'deki rüzgar hızlarının hesaplanması için; 2 ve 10 m'deki rüzgar hız verileri, yönlerine göre 12 sektöre ayrılıp bu hızlar kullanılarak her sektör için Hellman üstelleri hesaplanmıştır. Daha sonra bu üstellere göre sektör bazında 10 m'de ölçülen rüzgar hızları Hellman yaklaşımıyla, türbinin hub yüksekliği olan 45 m'ye ekstrapole edilmiştir. Ekstrapole edilen rüzgar hızlarından yararlanarak E-44'ün saatlik enerji üretim hesapları yapılmıştır.

Bir sonraki adımda ise rüzgar ve güneş enerjisi sistemlerinin günlük enerji üretimleri üzerinden, hibrit sistemin günlük enerji üretim değerleri, yılın her günü için hesaplanmıştır. Daha sonra, toplam kurulu güç 900 kW değerinde sabit tutulacak şekilde, rüzgar ve güneş sistemlerinin oranları adım adım değiştirilerek günlük yüzde üretimler bulunmuş ve bunların ortalaması alınarak bir yıl için, 900 kW kurulu güce sahip rüzgar/güneş hibrit enerji üretim sisteminin rüzgar ve güneş kurulu güç yüzdeleri belirlenmiştir.

Fotovoltaik pil olarak mono-kristal tercih edilmesi durumunda günlük enerji üretim değerlerinden yola çıkılarak yıllık üretimi maksimize etmek için kurulacak sistemin %72.02'sinin PV, %27.98'inin rüzgar enerjisine ayrılması gerektiği görülmüştür. Bu durumda sistem 736.43057 MWh/yıl enerji üretebilecektir. Bu da kurulu güce göre %9.3 kapasite faktörü olduğunu göstermektedir.

Fotovoltaik pil olarak poli-kristal tercih edilmesi durumunda, yıllı toplamda maksimum enerji üretimi için sistemin fotovoltaik kısmı %72.02 ve rüzgar kısmı da %27.98 olarak bulunmaktadır. Bu durumda yıllık toplam üretim 726.7068 MWh/yl olmaktadır. Bu da %9.2 kapasite faktörüne karşılık gelmektedir.

Fotovoltaik sistemde multijunction ince film seçilmesi durumunda yıllık üretimi maksimize etmek için fotovoltaik ısmın oranı %72.18 ve rüzgar kısmının oranı da %27.82 bulunmuştur. Bu sistemin bir yılda üreteceği hesaplanan enerji 736.22863 MWh/yıl olarak bulunmuştur. Kapasite faktörü de mono-kristal pilde olduğu gibi %9.3 çıkmaktadır.

Enerji üretimi açısından elde edilen oranlar ve enerji üretim değerleri birbirine çok yakın çıktığı için böyle bir rüzgar-güneş hibrit sistemi için genel olarak %72 fotovoltaik ve %28 rüzgar bileşeni kullanılmasının uygun olduğu söylenebilir. Bu da kurulu güç olarak yaklaşık 650 kW güneş ve 250 kW rüzgar anlamına gelir.

Fotovoltaik pil türünün seçiminde ise mono-kristal veya multijunction ince filmlerin hemen hemen aynı miktarda üretim sağlaması nedeniyle ikisinde biri tercih edilebilirse de panel alanları doalyısıyla fotovoltaik tarlanın kaplayacağı alan, fiyat ve bulunabilirlik verilen kararı etkileyecektir. Bu çalışmada plaka değerleri kullanılan fotovoltaik pillere bakılırsa 230W gücündeki mono-kristal pilin alanı 1.25 m^2, 270W gücünde poli-kristal pilin alanı 1.9 m^2 ve 145W gücündeki multijunction ince filmin alanı da 1.7 m^2 dir.

Her ne kadar rüzgar-güneş hibrit santralının kullanımı yıl içinde daha homojen elektrik üretimi sağlasa da İTÜ Ayazağa kampüsü için güneş enerjisinin öncelikli olduğu açıkca görülmektedir. Dolayısıyla kampüs dahilinde binaların çatılarına güneş panelleri kurulması öncelikli olarak önerilebilir. Çatı kurulumlarında yer sorunu öne çıktığı için, en yüksek kurulu gücü sağlamak için verimi en yüksek olan panel tipi olan mono-kristal kullanılması önerilebilir.

1. INTRODUCTION

1.1 Literature Review

Due to fact that wind and solar energy are sustainable renewable energy sources, many studies have been done on simultaneous working of these renewable energies to get benefits of their own complementary feature. Yang (2009), studied hybrid solar/wind stand-alone systems utilizing power banks and developed an optimal model. The purpose of using this system was power generation for a telecommunication station which was located along the coast of China. The optimal tilt angle of the PV panels, number of wind turbines and battery capacity were calculated. The annual expenses of the system was minimized without any extra inflictive loss. A genetic algorithm was used for model solution. Also, significant complementary between solar and wind energy was seen (Yang et al, 2009). An optimal sizing process for a similar system in Turkey was done by (Ekren et al, 2009). The possibility of producing enough energy for a seawater greenhouse in Oman with hybrid wind/solar energy system was estimated by (Mahmoudi et al, 2008). A possibility assessment of power generation and supply enough energy for energy demand of a typical commercial building with a hybrid solar/wind energy system.Various combination of wind energy system, photovoltaic panels, and diesel backup energy system investigated by (Elhadidy and Shaahid, 2004). The steady state performance of a hybrid wind/solar power system was analyzed in stand-alone and grid-dependent conditions with modeling the uncertainty of nature load by a probabilistic approach (Tina et al, 2006). An analysis of hybrid system containing wind and solar system has been doone by (Ingole and Rakhonde, 2015). Another analysis of a hybrid system with wind and solar sources which was located in jordan done by (Halasa and Asumadu, 2009). An analysis on the influence of the Deficiency of Power Supply Probability (DPSP), Relative Excess Power Generated (REPG), Energy to Load Ratio (ELR), fraction of PV and wind energy, and coverage of PV and wind energy against the system size and performance done by (Muralikrishna and Lakshminarayana, 2008).

An optimization on a wind-solar hybrid system which was located in india done by (Shanker and Sharma, 2012).They have used MATLAB for their simulations and they have compared stand-alone wind system and solar system with hybrid system.

1.2 Importance of Renewable Energy

The importance of the renewables energies can be discussed from two different points of view. First one is financial side. We can see the benefits of renewable energy in the several aspects of industry and business. The other one is environmental advantages of renewable energy and the effects of using these kinds of energies on the earth climate and humankind health.

1.2.1 Economical

Nowadays by increasing the price of fossil fuels, most of the industrial countries are trying to change their source of energy in their production procedure to the reliable sources. Renewable energy can be a correct choice in this case. Because renewable energy is providing more sustainability, this fact can help to make the price of energy to be more stable. Furthermore, in recent years the price of renewable technologies have decreased. As an illustration, the mean price of the solar panel has declined almost 60 percent since 2011 (Wei et al, 2010).Also, the cost of electricity which has been generated from wind energy dropped more than 20 percent during the years from 2010 to 2012 and more than 80 percent from 1980 to present (Akella et al, 2009). Although renewable energy would have more initial expenses for installation, once installed they operate at very low cost, without the need to fuel in most of the technologies. So, the prices of the renewable energy are stable over time. The other economic benefit of renewable energy is that this sector can create more job opportunities in different industrial sections because, renewable energy technologies are more labor-intensive than the fossil fuel industry which is capital-intensive.For instance, in the United States in 2011, the wind energy industry hired 75,000 full-time employees in various positions (Akella et al, 2009) and (Wiser and Bolinger, 2012). Also, more than 500 factories produce different parts of the wind turbine in the United States, and 70 percent of the wind turbine equipment are manufactured in domestic factories in 2011.This percentage was about 30 percent in 2006 (Akella et al, 2009).

Also in solar industry, about 100,000 people are employed on a part- time or full-time positions in the United States (Moreno and Lopez, 2008). Fluctuation in gas price during ten years in US is shown in Figure 1.1.

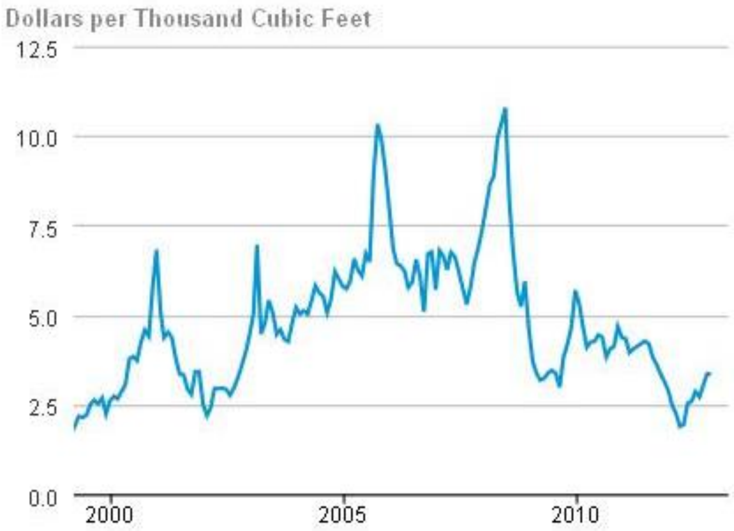


Figure 1.1 : US Natural gas wellhead price (US Natural gas wellhead price, 2013).

In addition, renewable energies are sustainable, and there is no end in this case. For example sun, as a source of solar energy is an infinite origin in a long term without any risk of ending while fossil fuels will be ended in this century. so it is the other reason for choosing this kind of energies as a source. Prediction of ending fossil fuels is shown in Figure 1.2.

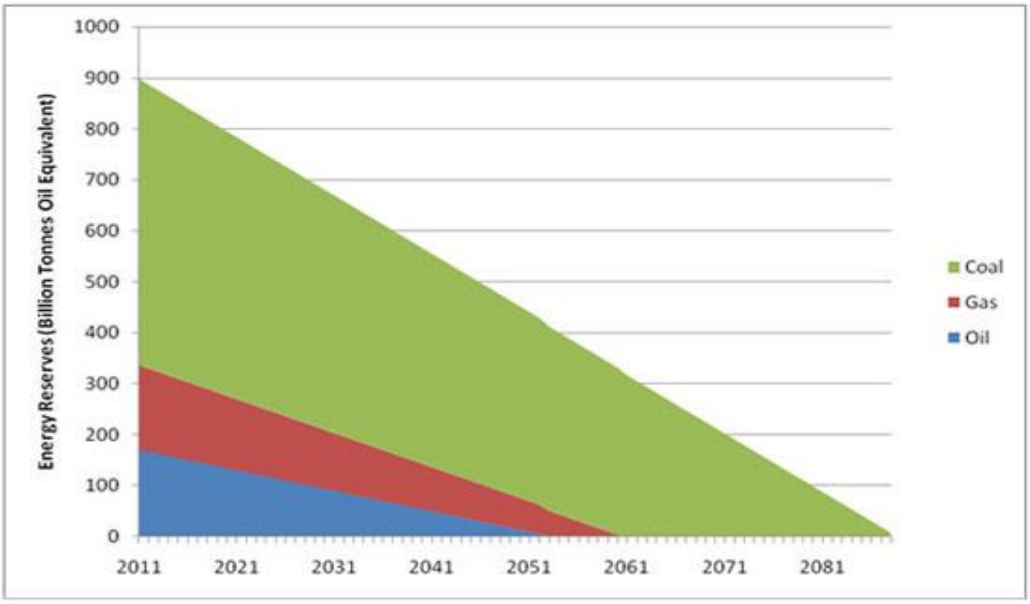


Figure 1.2 : Remaining reservers of oil and natural gas , oil and coal (The End Of Fossil Fuels, 2014).

1.2.2 Enviromental

Because of global industrialization, especially after the second world war in industrial countries, the generation of CO2 increased dramatically from 270 ppm to 450ppm (Tiwari and Mishra, 2012). This situation was the outcome of using fossil fuels in different phases such as solid, liquid and gas for power production. This situation has a negative effect on human being and living planets. If it is not controlled, the life of human and other lives will be in danger in the near future. In order to balance the ecological system to have more clean air, water, and food, renewable energy sources that are less polluting should be used to response to the energy demand of human beings across developed, developing and underdeveloped countries. Comparison of green house gases emission by renewable energies and fossil fuels is shown in Figure 1.3.

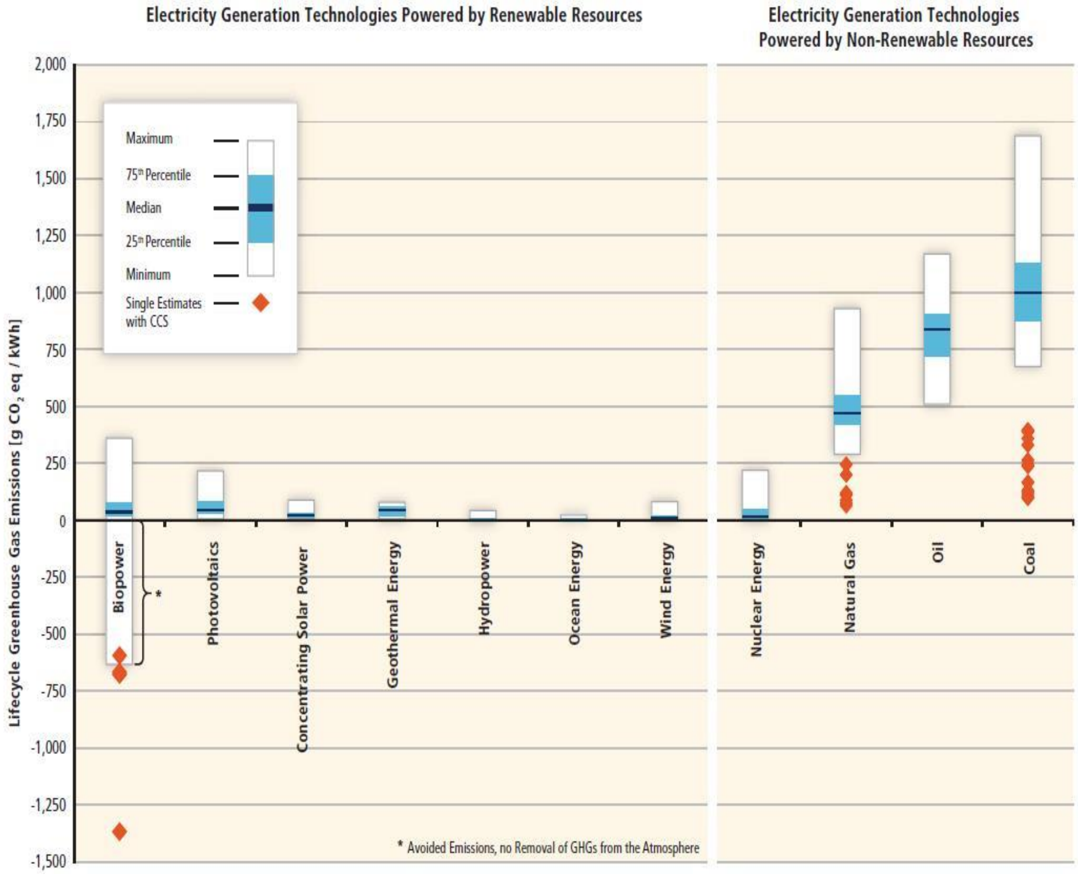


Figure 1.3 : Comparison of green house gases emission by renewable energies (Edenhofer et al, 2011).

As it has been mentioned, using fossil fuels can cause different environmental problems such as:

- Acid Rain
- Depletion of Ozone layer
- Global Warming and Climate change (Greenhouse Effect)

However, we can control these conditions by replacing fossil fuels with the environmental friendly alternatives, particularly renewable energy resources, as a potential solution. The electricity generated from renewable energy offers considerable public health benefits in comparison with fossil fuels. As it was mentioned above the ecological system polluted by coal and natural gas plants has side effects on the people's life quality such as breathing problems, neurological hurts, chronic heart diseases, and cancer. Generation of electricity without air pollution and any requirement to water are the other advantages of renewable energy especially wind and solar.

1.3 Wind Energy

The definition of wind is the motion of air which has kinetic energy. Wind energy has been being used for thousands of years ago. In the ancient civilizations, wind was being used for different purposes such as propelling ships, pulling up underground water from wells and grinding agriculture products. There are some evidences that proof ancient Egyptians, and Persians were using wind power. By 13th century using the wind power was popular in most of the Europe for grain gringing. An old windmill is shown in Figure 1.4.

Figure 1.4 : An old windmill in British isles (Pitstone Windmill, 2015).

There are some efforts to convert wind power to electricity from 19th century to now. There were some little electrical machines wich were generating electricity from wind energy and using for charging pills in the 1930s. But after 1980 the wind power technology developed significantly and made it possible to generate electricity from wind power in large scale. Nowadays wind power is one of the most economical methods of electricity generation, and the technology of that is developing day by day to make it more inexpensive and more reliable.

1.3.1 Energy and power in wind

wind energy is kinetic energy and kinetic energy is:

$$K = 0.5mv^2 \tag{1.1}$$

m has kg unit and $v$has m/s unit .

We can consider the wind passes through a circular ring with the area of A with the velocity of v. while air passes ring it creates a cylinder of air with a length.So a volume of air passes through ring in every second. By multiplying this volume with the density of air we can calculate the air mass passing the ring with kg/s unit.

$$m = \rho Arv^2 \tag{1.2}$$

By replacing this equation in equation (1.2) we have :

$$P = 0.5\rho Av^2 \tag{1.3}$$

Wind passing circular ring is shown in Figure 1.5. :

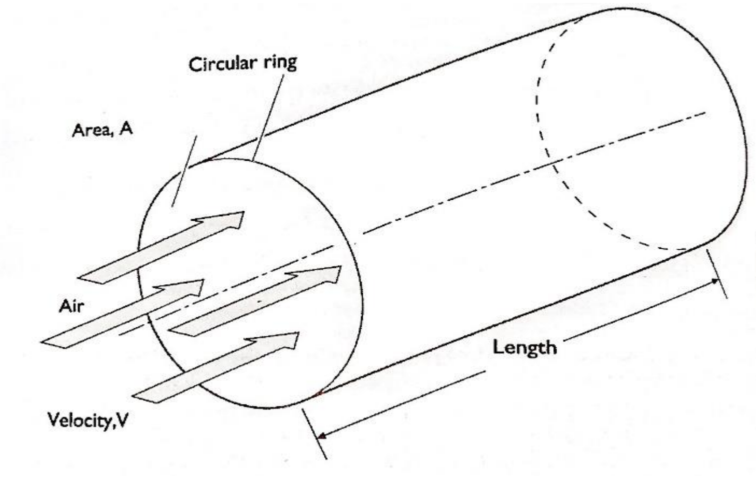


Figure 1.5 : Kinetic energy of wind (Boyle, 1996).

This equation depicts that the power of wind is depended to three items

- air density: air density changes with the height.
- cross-section area of passing the air
- cube of wind velocity: so it is an important factor in wind power. for example when the velocity changes from 2m/s to 4m/s power increases more than 100 percent .

1.3.2 Wind turbines

Different machines have been designed for harnessing the wind power which some of them are illustrated in the Figure 1.6.

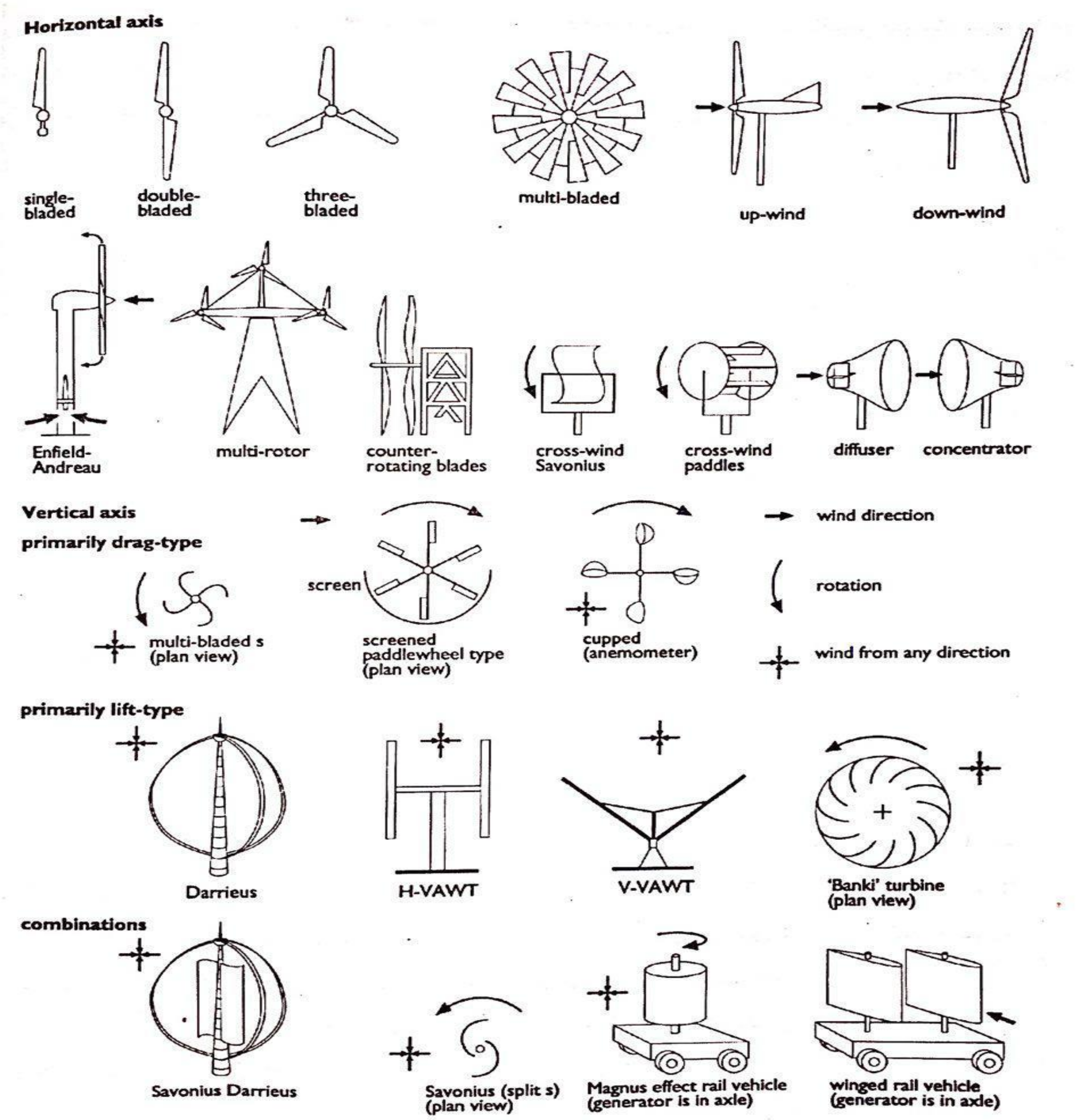


Figure 1.6 : Wind harnessing machines in history(Boyle, 1996).

Nowadays wind turbines are divided into two general types, vertical axis, and horizontal axis.Turbines with horizontal axis are axial flow and the vertical cross flow. The output power of these machines changes from 10 watts to 5 megawatts.

1.3.2.1 Horizontal axis wind turbine

Horizontal axis wind turbine (HAWT) mostly have two or three blades. Some turbines have more than three blades. This kind of turbines have tilted blades the usage of these turbines for pumping water in farms.Most of the rotor swept area in three blade turbines is empty so these turbines called low-solidity turbines.Most of the wind turbines are low-solidity HAWT which have rotors like airplanes. A wind turbine is shown in Figure 1.7.

Figure 1.7 : EnerconE-44 900KW wind turbine (Url-1).

1.3.2.2 Vertical axis wind turbine

Vertical axis wind turbines are not depended to the direction of the wind, so they do not need to change the rotor direction. VAWT has blades with constant chord and twist.In VAWT the blades are not high, so the wind speed is low as for result the output power of VAWT is low in comparison with HAWT. We can see some output power of VAWT is low in comparison with HAWT. We can see some examples of VAWT in Figure 1.8 Figure 1.9.

Figure 1.8 : The world tallest vertical axis turbine.

Figure 1.9 : A helical Darrius wind turbine.

1.3.3 Key factors of energy production from the wind

- The diameter of the area swept by rotor blades:The rotor blades of a wind turbine sweep through a circular area. Because we are dealing with circular area, increasing the rotor diameter, greatly increase power output.For Example, by doubling the rotor diameter quadruples power output. Rotor swept area of a wind turbine is shown in Figure 1.10.

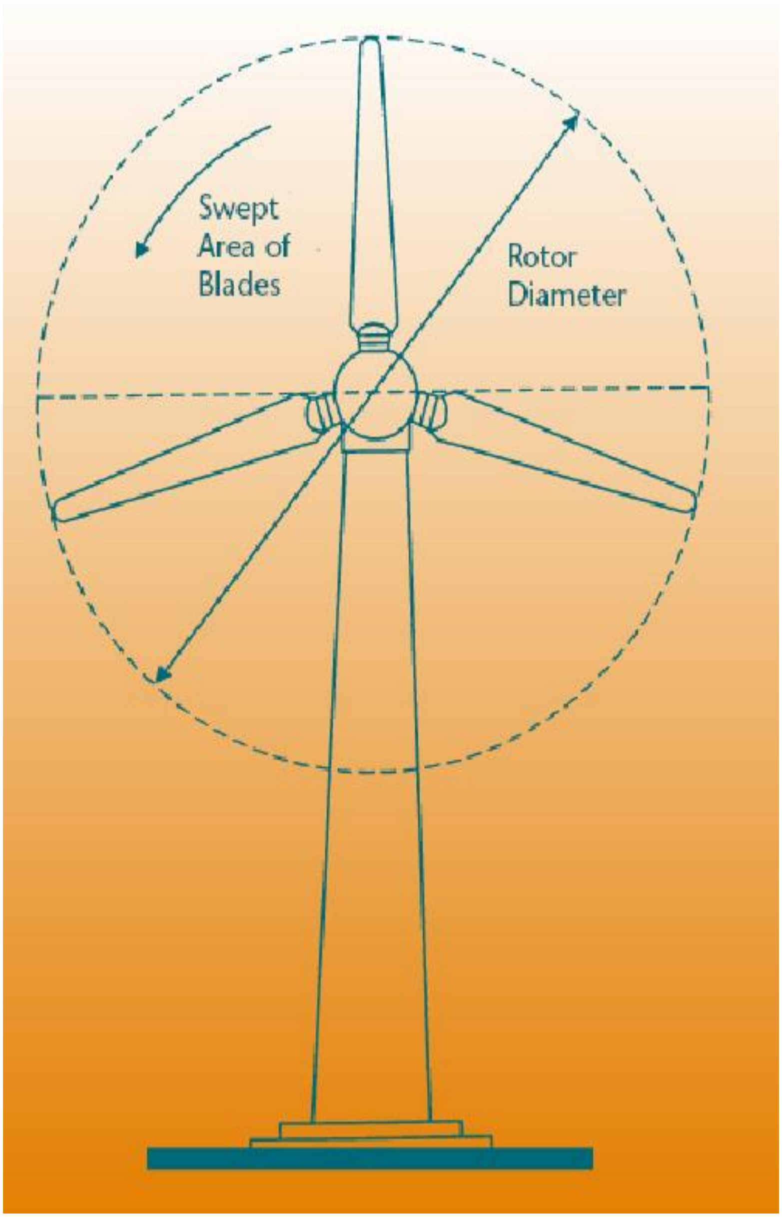


Figure 1.10 : Rotor swept area.

- The wind speed: to start with the length of time the wind is blowing above the cut-in speed is a critical factor .also small changes in wind speed lead to large variation in available power. A 10 percent increase in wind speed can cause an increase in power of about 30 percent.

- The variation of wind speed over time at site: the total energy generated by wind energy system over a period depends on the distribution and variability of wind speed over time .the annual average wind speed at a site is more important than the speed at any given moment.
- The air density: wind power is related to air density directly, has the inverse relation with temperature.
- The Betz limit: In the energy extraction from the wind, its velocity declines.In theory, if all the energy of wind were taken, the wind would stop. However, it is impossible to extract the all the energy from the wind .the most energy that an ideal wind energy system can be extracted is about 59 percent. This value is known as Betz limit.

1.3.4 Power extracted from the wind

The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers.

$$P_0 = 0.5\dot{m}(v^2 - v_0{}^2) \tag{1.4}$$

The air speed is discontinuous from v to v0 at the plane of the rotor blades in the macroscopic sense. The mass flow rate of air through the rotating blades is, therefore derived by multiplying the density with the average velocity.

$$\dot{m} = \rho A \frac{v+v_0}{2} \tag{1.5}$$

$$P_0 = 0.5\ \rho A \frac{v+v_0}{2}(\dot{v}^2 - v_0{}^2) = 0.5\rho A v^3 \frac{\left(1+\frac{v_0}{v}\right)\left[1-(\frac{v_0}{v})^2\right]}{2} \tag{1.6}$$

$$C_{p=}\frac{\left(1+\frac{v_0}{v}\right)\left[1-(\frac{v_0}{v})^2\right]}{2} \tag{1.7}$$

$$P_0 = \frac{1}{2}\ \rho A v^3 C_p \tag{1.8}$$

C_p is power coefficient of rotor.C_p depends on the ratio of the downstream to upstream wind speed. The plot of power coefficient versus $(\frac{v_0}{v})$ shows that cp has the single maximum- value function. It has the maximum value of 0.59 when the ($\frac{v_0}{v}$) is one third. The relation between C_p andV/Vo is demonstrated in Figure 1.11.

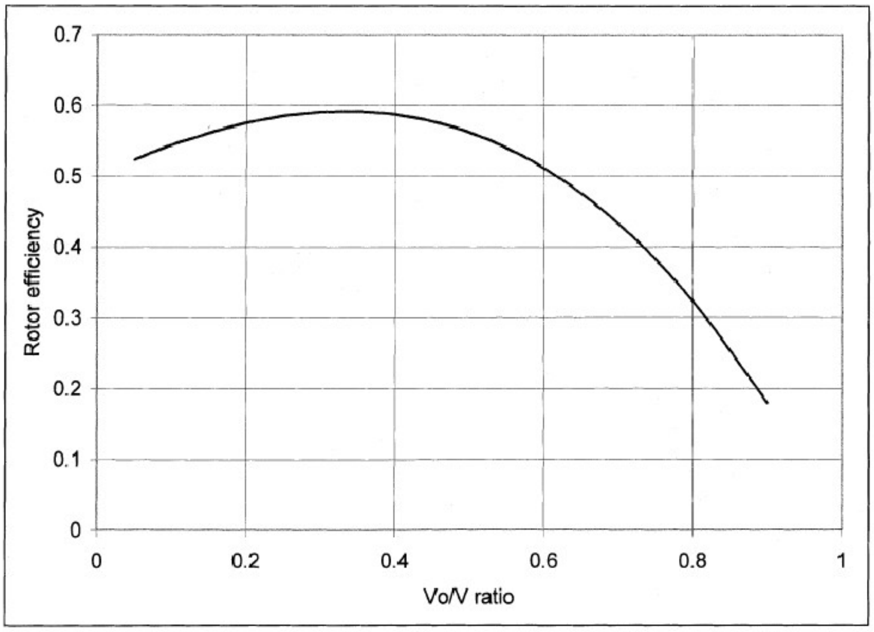


Figure 1.11 : Relation between Cp and V/Vo.

The maximum power is extracted from the wind at that speed ratio when the upstream and downstream wind speed equals one-third .under this condition:

$$P_0 = \frac{1}{2}\,\rho A v^3 0.59 \qquad (1.9)$$

The theoretical maximum value of C_p is 0.59 in practical designs; the maximum achievable C_p is below 0.5. The Wind speed & output power cure and wind speed Cp curve is shown in Figure 1.12.

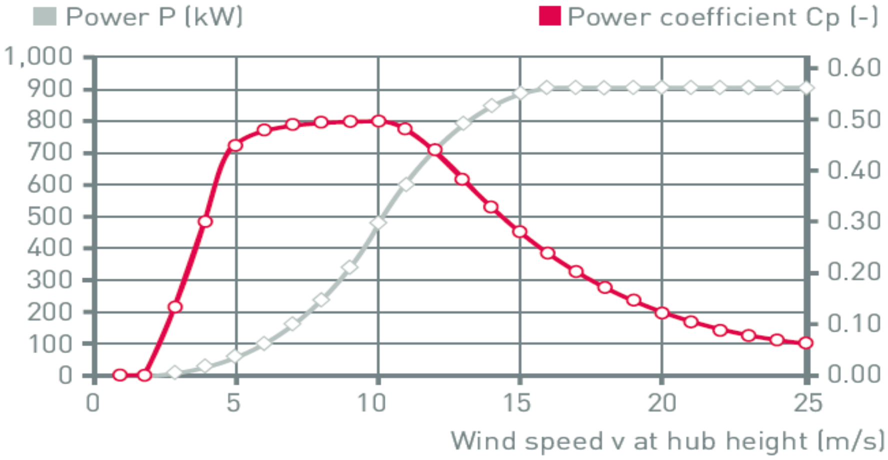


Figure 1.12 : Wind speed & output power cure and wind speed Cp curve (Url-1).

1.3.5 Height effect on wind speed

The increase in wind velocity with height is one of the most important phenomena on the utilization of wind energy. Moving air masses friction against earth surface decelerates wind speed. We can use Hellman approximation for calculation of wind speed at different altitudes.

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^{\alpha} \tag{1.10}$$

In this equation v_2 is wind speed at elevation and v_1 is wind speed at elevation h_1 with m/s unit.$h_2$is requested height and h_1 is reference height both of them are in m.Also,α is Hellman's exponent. Hellman exponent for different areas are shown in Table 1.1.

Table 1.1 : Hellman exponent.

Terrian Type	Hellman's Exponent (Friction Coefficient) α
Lake, ocean and smooth hard ground	0.10
Foot high grass on level ground	0.15
Tall crops, hedges and shrubs	0.20
Wooded country with many tress	0.25
Small town with some treesand shrubs	0.30
City area with tall buildings	0.40

1.4 Solar Energy

We discussed the sustainability of solar energy in previous sections now we want to describe the calculation of solar energy which we can harness in the earth. Receiving irradiances from the sun varies during a day. Also it changes along the year. It depends on several factors. Furthermore, the system of solar energy conversion does not convert all of the receiving energy to the electricity, and we have some limitation. First of all, we want to describe the factors which are effective in solar energy conversion system. The time and the season are important. Also, geographical information is significant. We use photovoltaic panels for solar energy conversion. The position of these panels and solar angle that depends on time and location, are effective in the solar power calculation.Solar angle are shown in Figure 1.13.

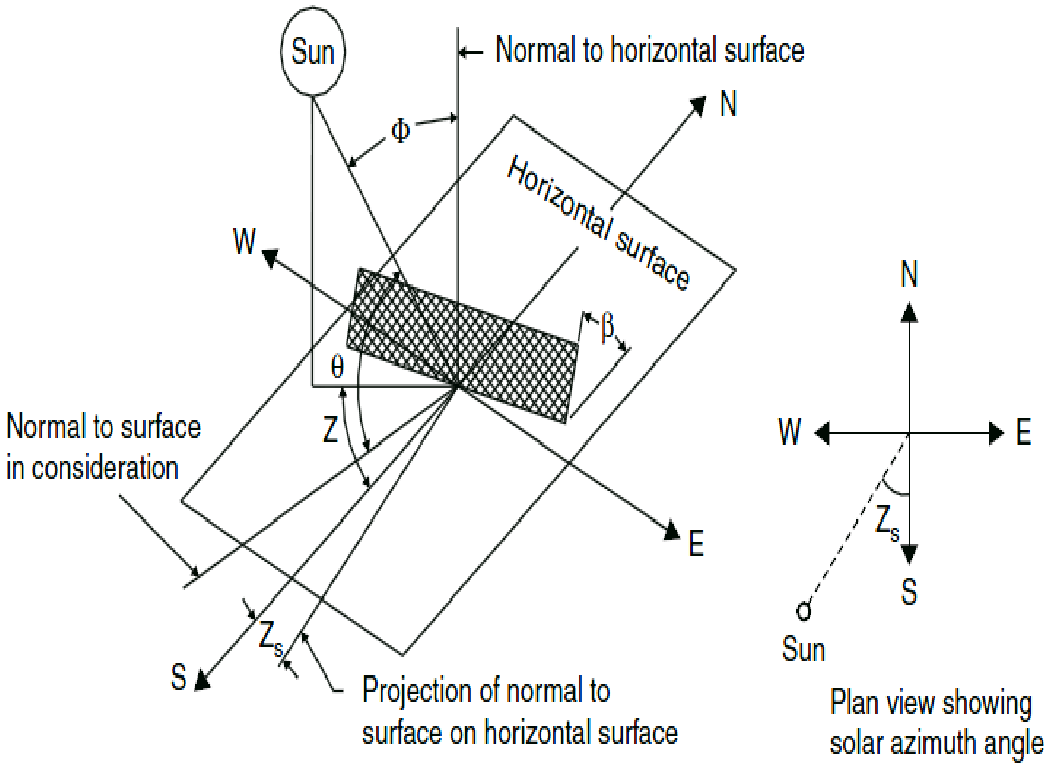


Figure 1.13 : Solar angle diagram (Kalogirou, 2009).

1.4.1 Incidence angle and parameters

For calculation of the amount of sun's ray reaching on a horizontal surface, we have to write some trigonometric relations between the position of sun and panel coordinates on the earth.

In this case, we have to calculate the solar incidence angle which is the angle between the sun's irradiance and the normal on a panel.

$$\cos\theta = \sin(L-\beta)\sin(\delta) + \cos(L-\beta)\cos(\delta)\cos(h) \tag{1.11}$$

In this equation β is the suface tilt angel from the horizontal, L is local latitude and δ is declination angle. Also h is known as hour angle.

The equation of declination of sun is :

$$\delta = 23.45\sin\left[\frac{360}{365}(284+N)\right] \tag{1.12}$$

N is number of day.

The curve of declination of sun during a year is shown in Figure 1.14. Also, day number and recommended average day for each month is given in Table 1.2.

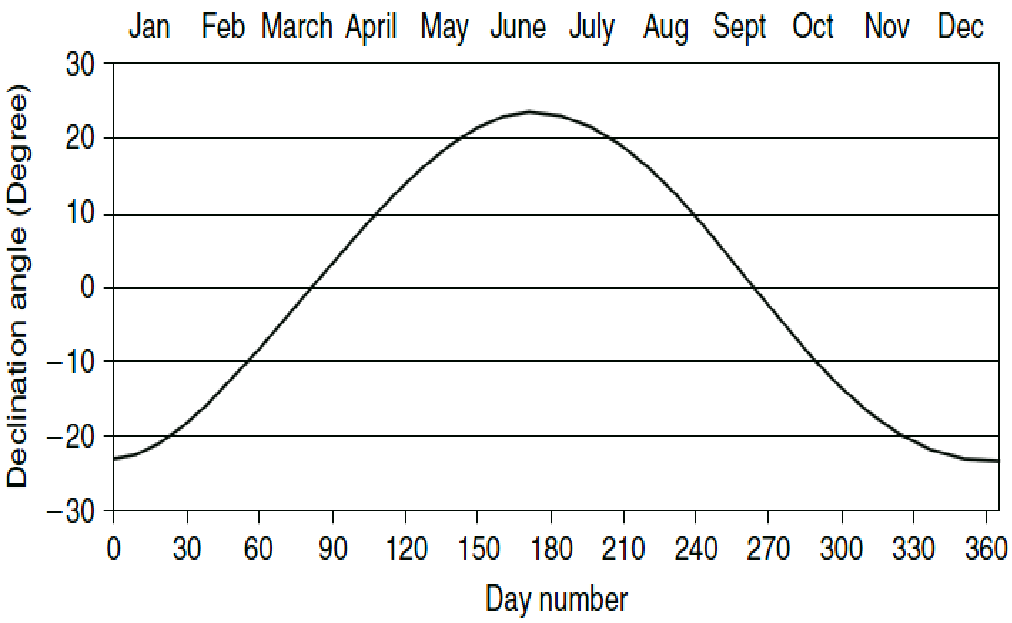


Figure 1.14 : Declination of sun (Kalogirou, 2009).

Table 1.2 : Day number and recommended average day for each month (Kalogirou, 2009).

Month	Day Number		Average Day of the Month	
		Date	N	δ(deg.)
January	i	17	17	-20.92
February	31 + i	16	47	-12.95
March	59 + i	16	75	-2.42
April	90 + i	15	105	9.41
May	120 + i	15	135	18.79
June	151 + i	11	162	23.09
July	181 + i	17	198	21.18
August	212 + i	16	228	13.45
September	243 + i	15	258	2.22
October	273 + i	15	288	-9.60
November	304 + i	14	318	-18.91
December	334 + i	10	344	-23.05

Hour angle: The hour angle, h, of a point on the earth's surface is defined as the angle through which the earth would turn to bring the meridian of the point directly under the sun.The hour angle at local noon is zero, with each 360/24 or 15 degrees of longitude equivalent to 1 hour so that h can obtain from apparent solar time (AST).

$$h = (AST - 12)15 \tag{1.13}$$

1.4.2 Photovoltaic systems

Photovoltaic modules convert the sunlight directly into the electricity without any need to heat engine or rotating machines.PV systems have no moving parts, so these kinds of systems have no maintaining expenses. The photovoltaic panels are composed of two, unlike semiconductors. One of them is semiconductor type n, and the other one is type p. In photovoltaic panels at p-n junctions when the photons of light reach the junction, they transmit their energy to the electrons of the PV so electrons jump to upper energy band which is conduction and with their motion in PV the can create an electrical current.The operation of a photo voltaic cell is shown in Figure 1.15.

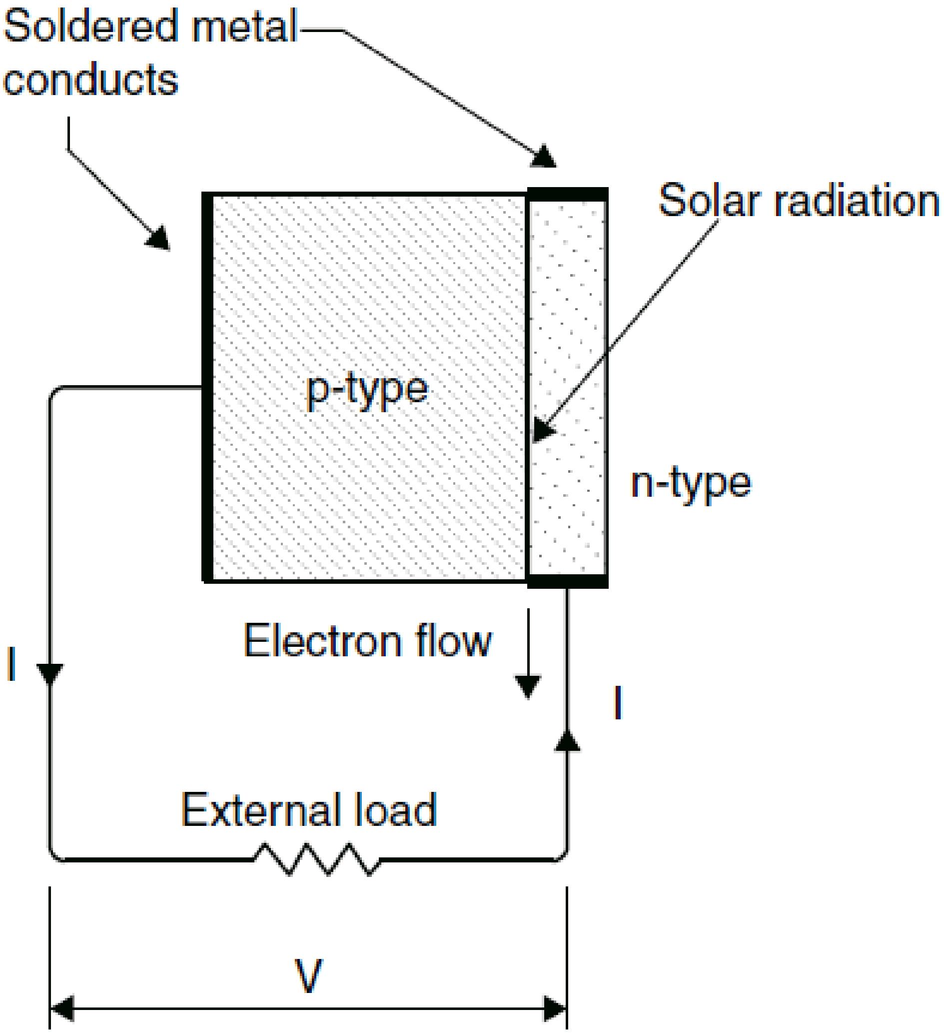


Figure 1.15 : Photovoltaic effect (Kalogirou, 2009).

The photovoltaic cells have an electrical model. These cells act as a diode in an electrical circuit. We can see the electrical model of PV cells in Figure 1.16.

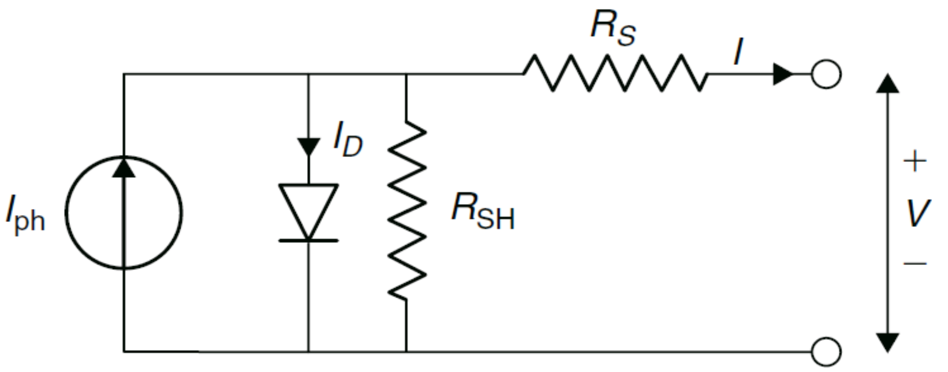


Figure 1.16 : Single solar cell model (Kalogirou, 2009).

The current equations of this circuit is:

$$I = I_{ph} - I_D = I_{ph} - I_0\left\{exp\left[\frac{e(V+IR_s)}{kT_C}\right] - 1\right\} - \frac{V+IR_S}{R_{SH}} \tag{1.14}$$

The shunt resistance is much bigger than the load resistance. However, the series resistance is much smaller than the load resistance. So, by ignoring these distances we have:

$$I = I_{ph} - I_D = I_{ph} - I_0\left[exp\left(\frac{eV}{kT_C}\right) - 1\right] \tag{1.15}$$

where the k is Boltzmann gass constant ,$T_C$is absolute temperature of cell (K), e is electronic charge,V is voltage imposed across the cell and I_0 is dark saturation current.

The I-V characteristic of a cell under a certain sun's rays at a constant temperature is shown in Figure 1.17.

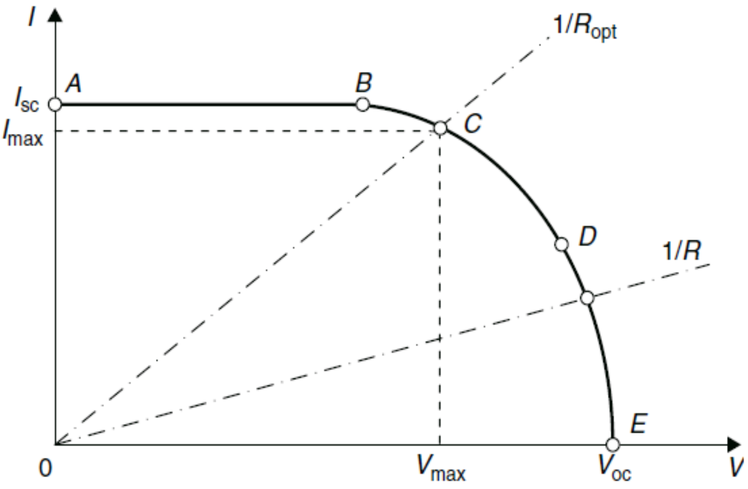


Figure 1.17 : Current-voltage curve of photovoltaic cells (Kalogirou, 2009).

Because of diode characteristic of solar cell $I_{sc}$and V_{oc} are calculated from these relations:

$$I_{sc} = I_0(1 + \alpha\Delta T) \tag{1.16}$$

$$V_{oc} = V_0(1 + \beta\Delta T) \tag{1.17}$$

α and β are coefficients of teprature for current and voltage . α is positive and β is negative and $\alpha << \beta$.

The Figure 1.17 depicts that the current from a solar cell pertains to the external voltage applied and the amount of sun's ray on the cell. , the current is at maximum (short-circuit current, Isc), when the cell is short-circuited, and the voltage across the cell equals to zero. When the solar cell circuit is open, the voltage is at its maximum (open-circuit voltage,Voc), and the current equals to zero. In the both conditions the p (the production of current and voltage) is zero. The output power is nonzero between open circuit and short circuit. Figure 1.17 illustrates that If the PV cell's terminals are connected to a variable resistance, R, the operational point is defined by the intersection of the I-V characteristic of the solar cell with the load I-V characteristics. According to this figure for a resistive load, the load characteristic is a straight line with a slope 1/V =1/R. If the load resistance is small, the cell operates in the region AB of the curve, where the solar cell acts as a constant current source, approximately equal to the short-circuit current. While, if the resistive load is large, the cell works the region DE of the curve, where the cell acts more like a constant voltage source, almost equal to the open circuit voltage.The output power equals to the product of the current and voltage.If we did this multiplication and plotted the result on the same axes, then Figure 1.18 can be procured.

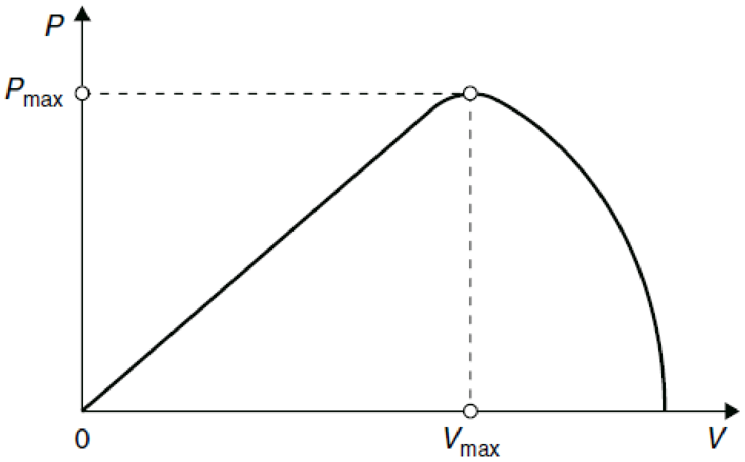


Figure 1.18 : Power-voltage curve for photovoltaic cells (Kalogirou, 2009).

The maximum power passes from a maximum power point (point C on figure), at which point the load resistance is optimum,Ropt,and the power dissipated in the resistive load is maximum and given by:

$$P_{max} = I_{max}V_{max} \tag{1.18}$$

In this case, we can calculate another parameter which name is filled factor and can be driven from this equation:

$$FF = \frac{P_{max}}{I_{sc}V_{op}} = \frac{I_{max}V_{max}}{I_{sc}V_{oc}} \tag{1.19}$$

Also, from that relation we can calculate the power temperature coefficient and it is:

$$P_{ideal} = I_{sc}V_{oc} = I_0(1+\alpha\Delta T)\, V_{oc}(1+\beta\Delta T) \tag{1.20}$$

$$P_{ideal} \cong P_0(1 + (\alpha + \beta)\, \Delta T) \tag{1.21}$$

The expression $(\alpha + \beta)$ known as power temperature coefficient.

The fill factor decreases as the cell temperature increases. And it increses as irridiance increses. So the curves I-V characterstics of solar cell changes like Figure 1.19 . Also, I-V curve is shown in Figure 1.20.

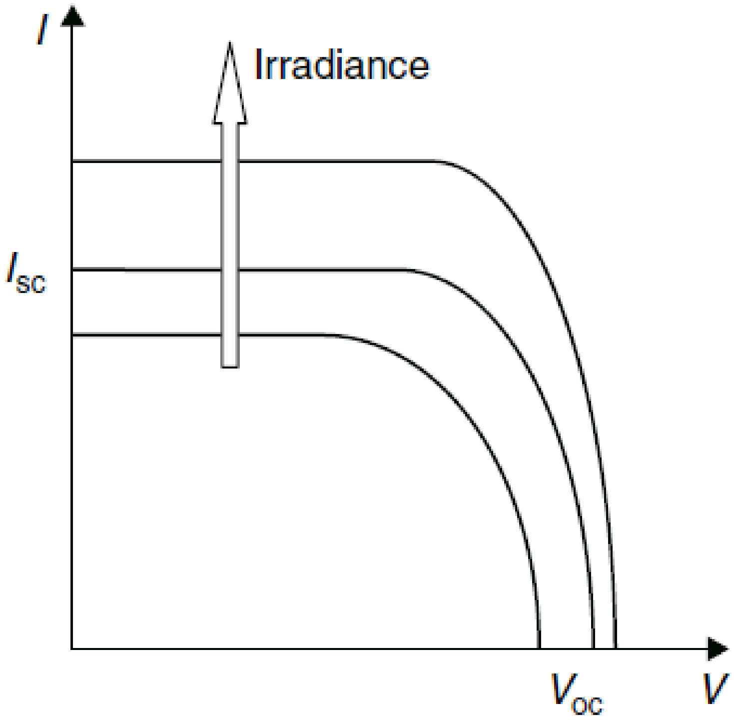


Figure 1.19 : Effect of increased irradiation (Kalogirou, 2009).

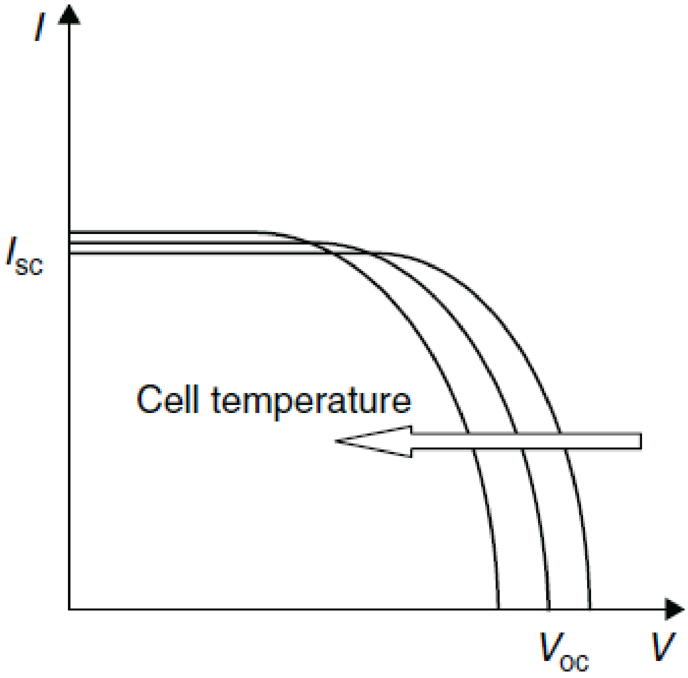


Figure 1.20 : Effect of increased cell temperature(Kalogirou, 2009).

As can be seen, two similar solar cell in parallel connection the voltage remains the same, but the current is doubled; and in series connection, the current remains the same, but the voltage is doubled. We can see the Schematic diagram of a PV module consisting of N_{pm} parallel branches, each with N_{sm} cells in series in Figure 1.21.

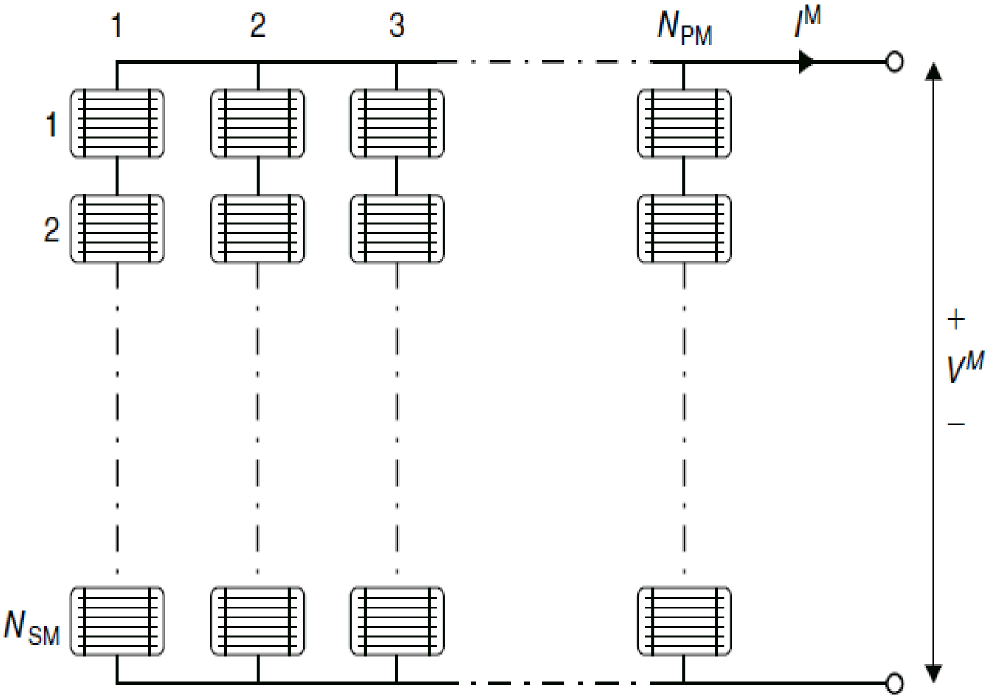
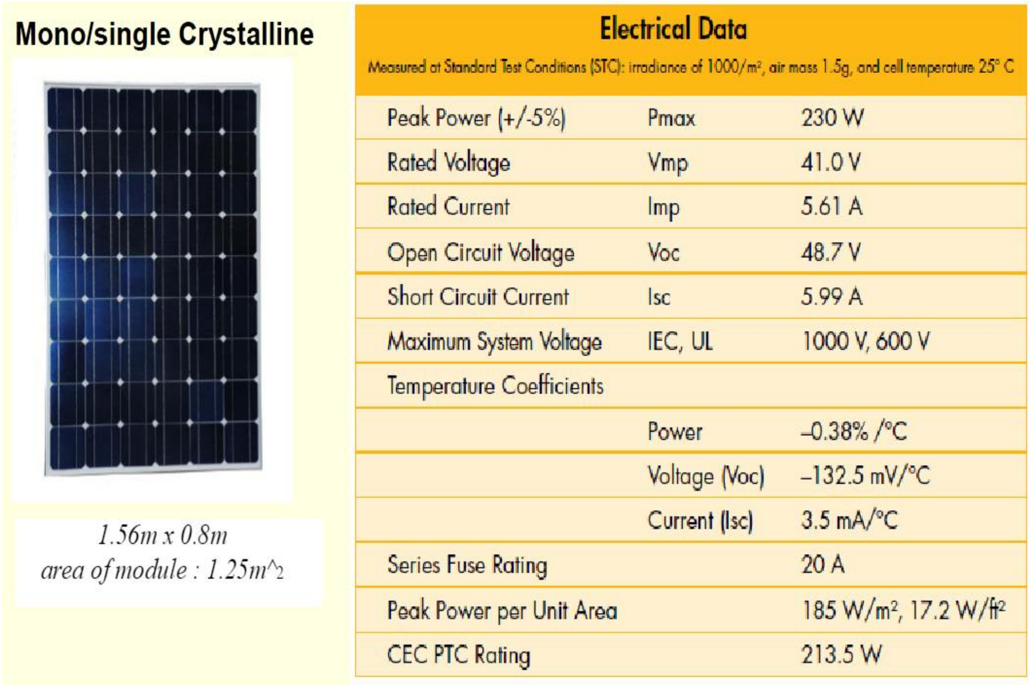


Figure 1.21 : Schematic diagram of a PV module (Kalogirou, 2009).

1.4.3 Types of photovoltaic technology

In this section we will describe the types of photovoltaic cells that we have uses in this study.

- Mono crystalline:These cells are made from pure monocrystalline silicon. These type photovoltaic cells have high efficiency, which is approximately is 18%. However, the price of monocrystals are expensive. We can see the cataloge information of mono crystalline module in the Figure 1.22.



Mono/single Crystalline

1.56m x 0.8m
area of module : 1.25m^2

Electrical Data

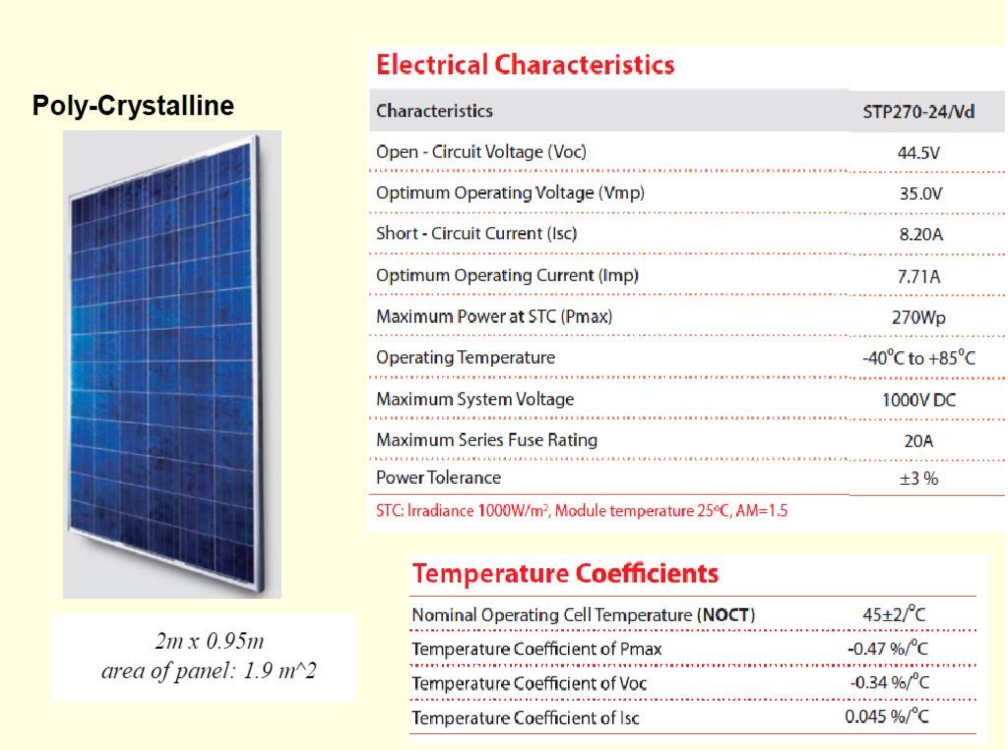
Measured at Standard Test Conditions (STC): irradiance of 1000/m², air mass 1.5g, and cell temperature 25° C

Peak Power (+/-5%)	Pmax	230 W
Rated Voltage	Vmp	41.0 V
Rated Current	Imp	5.61 A
Open Circuit Voltage	Voc	48.7 V
Short Circuit Current	Isc	5.99 A
Maximum System Voltage	IEC, UL	1000 V, 600 V
Temperature Coefficients		
	Power	–0.38% /°C
	Voltage (Voc)	–132.5 mV/°C
	Current (Isc)	3.5 mA/°C
Series Fuse Rating		20 A
Peak Power per Unit Area		185 W/m², 17.2 W/ft²
CEC PTC Rating		213.5 W

Figure 1.22 : Electrical data of Mono-crystaline.

- Poly crystalline : Polycrystalline cells are made up of multiple crystals and are generally less expensive to manufacture than mono cells. The gap in performance has narrowed significantly over the years to the point where they are very close. Since Polycrystalline panels are made up of several crystals, this means that they also absorb less sunlight and produce slightly less than mono cells per metre squared.. These are cheaper than mono crystalline and the efficiency of these cells is about 14 percent.the information poly are shown in Figure 1.23.

- Multijunction : These types are more economic but low efficiency . The electrical information and sample catalog of these cells are given in Figure 1.24.



Poly-Crystalline

2m x 0.95m
area of panel: 1.9 m^2

Electrical Characteristics

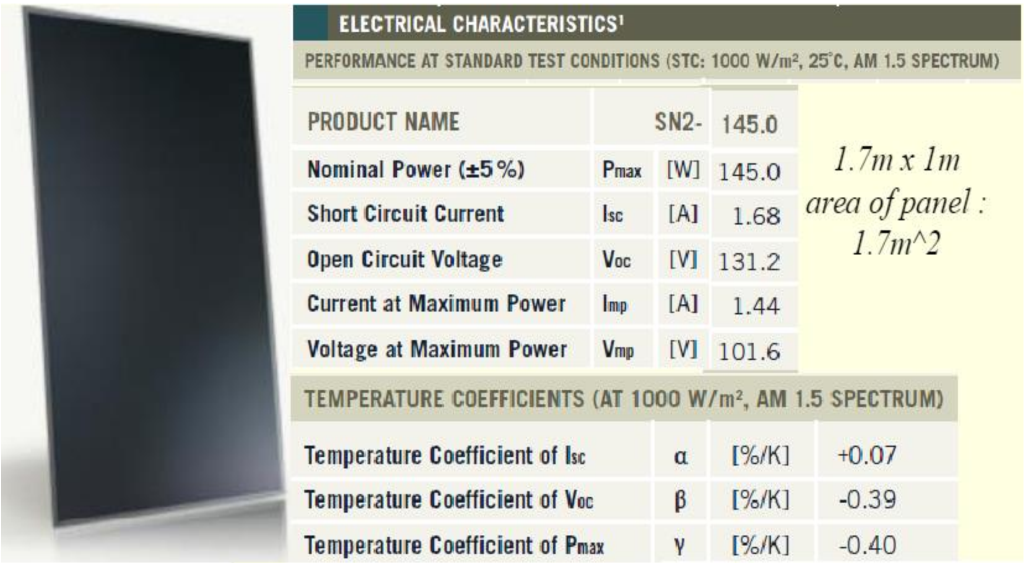
Characteristics	STP270-24/Vd
Open - Circuit Voltage (Voc)	44.5V
Optimum Operating Voltage (Vmp)	35.0V
Short - Circuit Current (Isc)	8.20A
Optimum Operating Current (Imp)	7.71A
Maximum Power at STC (Pmax)	270Wp
Operating Temperature	-40°C to +85°C
Maximum System Voltage	1000V DC
Maximum Series Fuse Rating	20A
Power Tolerance	±3 %

STC: Irradiance 1000W/m², Module temperature 25°C, AM=1.5

Temperature Coefficients

Nominal Operating Cell Temperature (**NOCT**)	45±2/°C
Temperature Coefficient of Pmax	-0.47 %/°C
Temperature Coefficient of Voc	-0.34 %/°C
Temperature Coefficient of Isc	0.045 %/°C

Figure 1.23 : Electrical data of Poly-Crystaline.



ELECTRICAL CHARACTERISTICS[1]

PERFORMANCE AT STANDARD TEST CONDITIONS (STC: 1000 W/m², 25°C, AM 1.5 SPECTRUM)

PRODUCT NAME	SN2-		145.0
Nominal Power (±5 %)	Pmax	[W]	145.0
Short Circuit Current	Isc	[A]	1.68
Open Circuit Voltage	Voc	[V]	131.2
Current at Maximum Power	Imp	[A]	1.44
Voltage at Maximum Power	Vmp	[V]	101.6

1.7m x 1m
area of panel : 1.7m^2

TEMPERATURE COEFFICIENTS (AT 1000 W/m², AM 1.5 SPECTRUM)

Temperature Coefficient of Isc	α	[%/K]	+0.07
Temperature Coefficient of Voc	β	[%/K]	-0.39
Temperature Coefficient of Pmax	γ	[%/K]	-0.40

Figure 1.24 : Electrical data of Multijuction.

1.5 Hybrid Systems

In this section, we will discuss the hybrid system and describe its advantages. A hybrid renewable energy system consists two or more renewable energy sources that work simultaneously and generate energy more permanently.

In this study, we have chosen the solar-wind hybrid system because this combination provides some significant advantages and we can drive the benefits of these type of sources at the same instant.

According to the previous descriptions wind and solar energies have their own benefits. Also, the combination of wind and solar systems complement each other.

Due to the fact that the peak electricity generation of a wind system usually occurs in winter, however, a solar system reaches to its maximum level of the electricity generation generally in summer.

This difference in the time of peak generation causes the power generation of such a hybrid system to be more consistent also under this conditions there are fewer fluctuations during power generation along a year. Hourly wind speed during a year is shown in Figure 1.25.

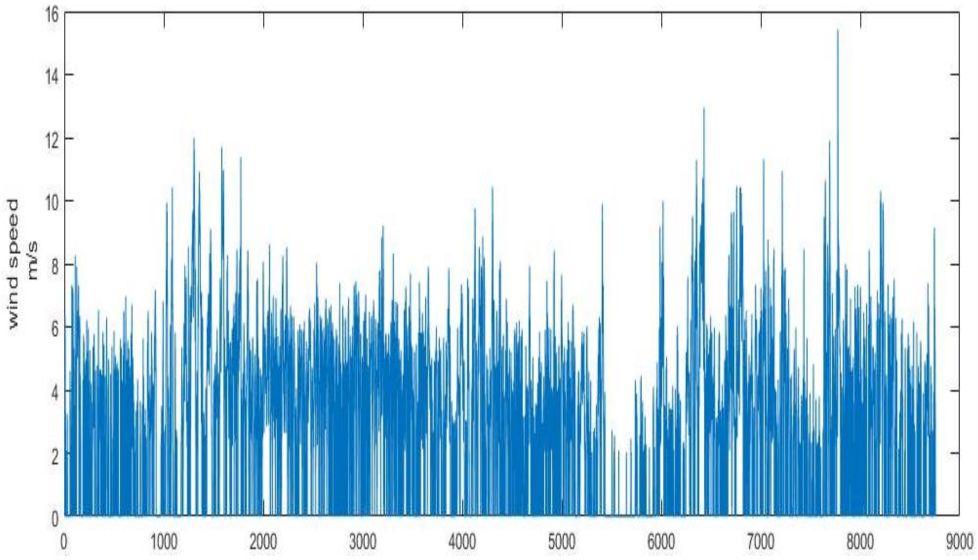


Figure 1.25 : Hourly variation of wind speed in one year.

As it is seen, the wind speed is more powerful in the winter. We know power generation of wind system, is proportional to the cube of wind speed. Thus, power generation is greater in winter.

The annual solar irradiance variation is shown in Figure 1.26. Solar irradiances are in their high level in summer. So the power generation in solar system reaches its maximum in summer. It means that more energy can be extracted from the sun in summer. This condition is exactly opposite of wind energy conditions.

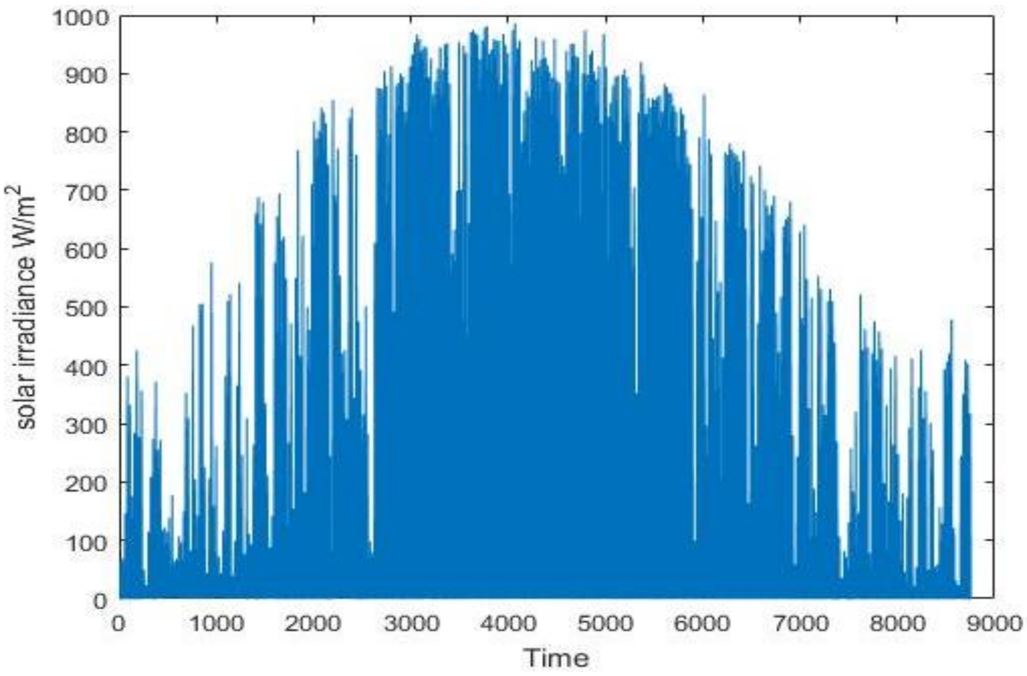


Figure 1.26 : Variation of solar irradiance.

By adding the output power of these two systems the final result of this combination is more constant than two component subsystem.

1.5.1 The hybrid system components

- Photovoltaic modules: these modules convert the sun rays to direct electrical current. The output current and voltages can change with a series or a parallel combination.
- Wind Turbine: changes the wind energy to electricity, usually it is a AC electrical machine.
- DC-AC inverter: the output of photo voltaic system in DC current so we have to reactifir DC to AC. Inverter does this function.
- Batteries : for storing the energy we used the batteries.
- Charge controller regulator : prevent the PV and wind turbine from over charging the batteries.
- Backup power resource can come either from a generator or from the utility grid when too much energy is consumed or when there has not been enough renewable energy coming into the system.

1.5.2 Establishment of a wind/solar hybrid unit

The hybrid power plant consists two complete generating plants, a PV solar cell plant and a wind turbine system.The output of these systems are connected in parallel to a 220V AC line.The output of PV panels connected to the inverter.It converts the DC electricity to AC. also the output of wind turbine connected to AC filter which stabilizes the voltage at 220V and 50Hz. The battery is charged through the DC line which is connected to photovoltaic panels. At end of the AC line it is connected to the load (Subrahmanyam et al, 2012a). A simple hybrid solar wind system is shown in Figure 1.27.

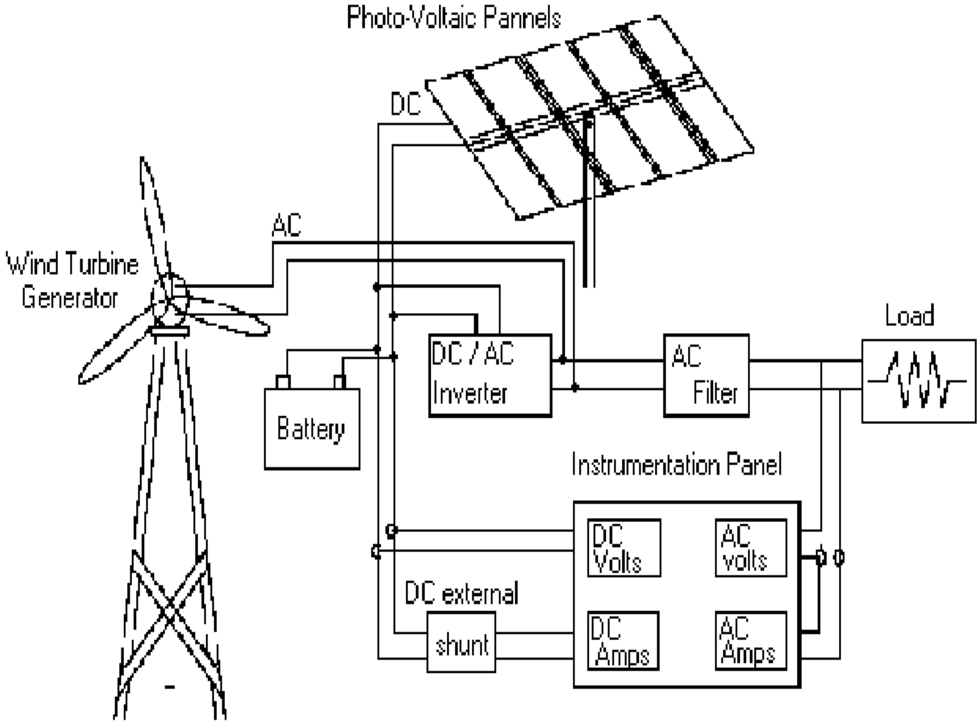


Figure 1.27 : Simple hybrid solar wind system (Subrahmanyam et al, 2012b).

2. DESCRIBING LOCATION, INPUT DATA AND CALCULATION METHOD

In this case, we want to describe our incoming data and location.

2.1 Location

This hybrid plant is located in Istanbul Technical University in the Sariyer district with 41.191111 latitudes and 29.009444 longitudes. The location of University is shown in Figure 2.1.

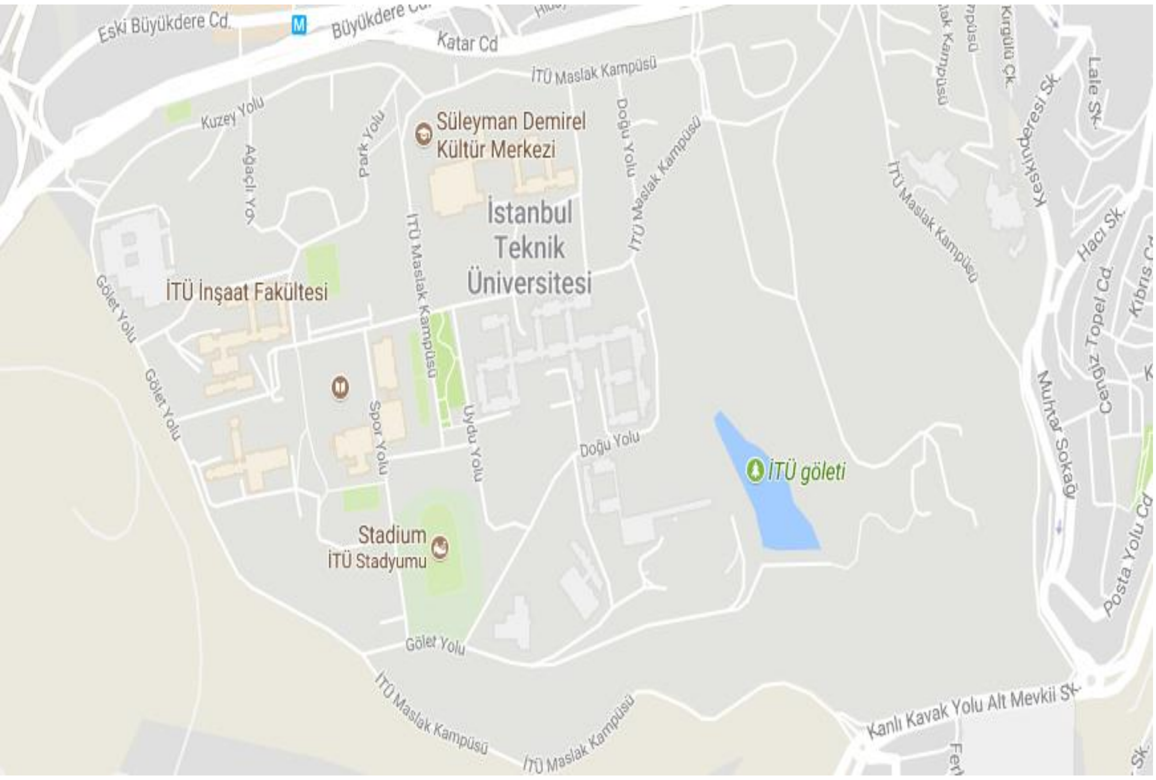


Figure 2.1 : ITU location (Url-2).

2.2 Data

Our data which are wind speed and solar irradiance and temperature, are collected from meteorology station which was located on the campus. All of these data belongs to 1st of January to 31 December of 2003.

2.2.1 Wind speed data

In the figure below the hourly variation of wind speed in the year 2003 is shown in Figure 2.2.

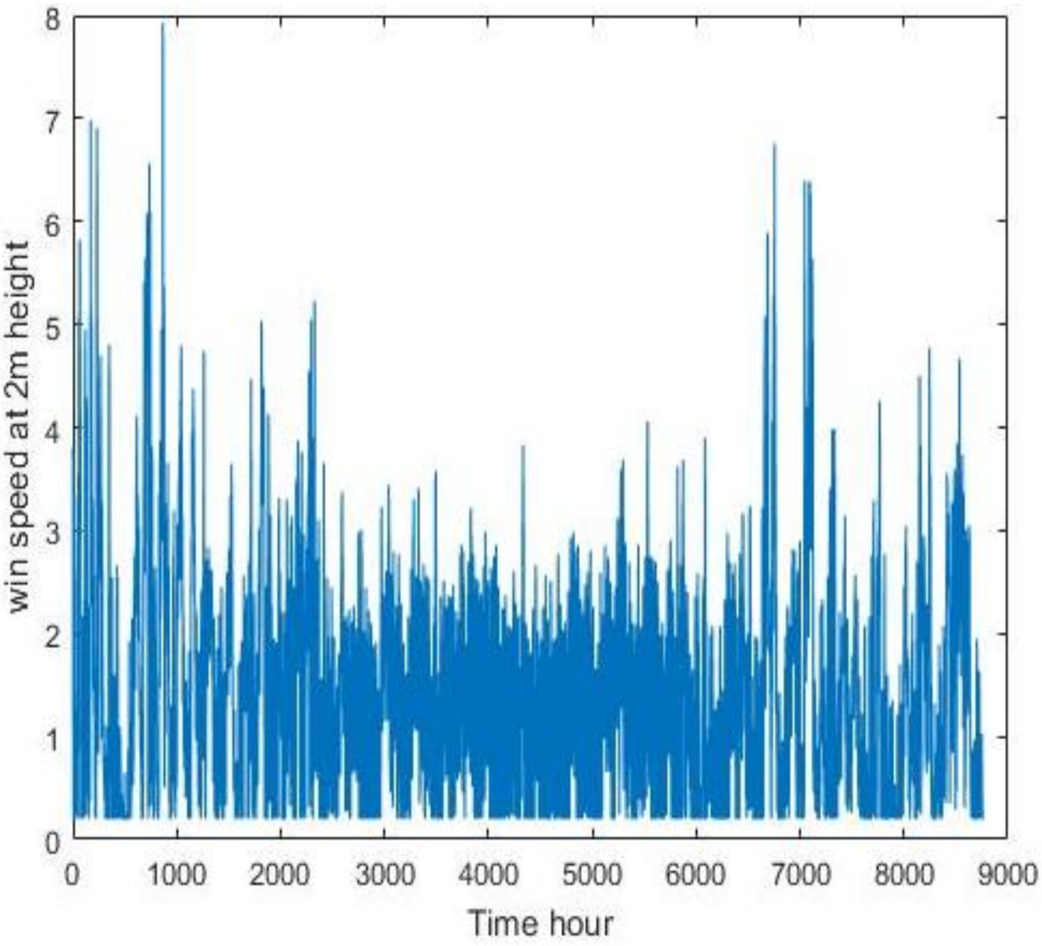


Figure 2.2 : Hourly wind speed variation.

According to the above figure the wind speed is stronger in winter. Also maximum value of wind speed at this height is 7.9 m/s and minimum value is 0.02 m/s also mean value is 1.4 m/s.

2.2.2 Solar irradiances

The amount of annual solar irradiances which was measured by meteorology station’s pyranometer is illustrated in Figure 2.3. These data are annual data and hourly data. The total number of hours during one year is 8760 hour. It means that the average value of the wind speed or solar irradiances is recorded in one hour.

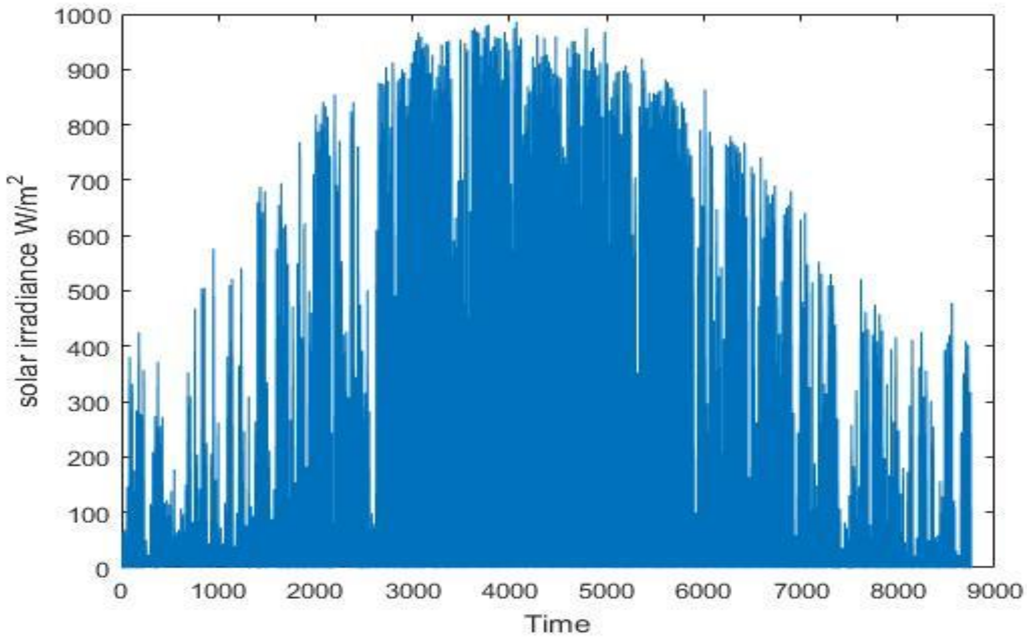


Figure 2.3 : Hourly solar irradiances variation.

Also in Figure 2.4 we can see variation of temperature during the year 2003.

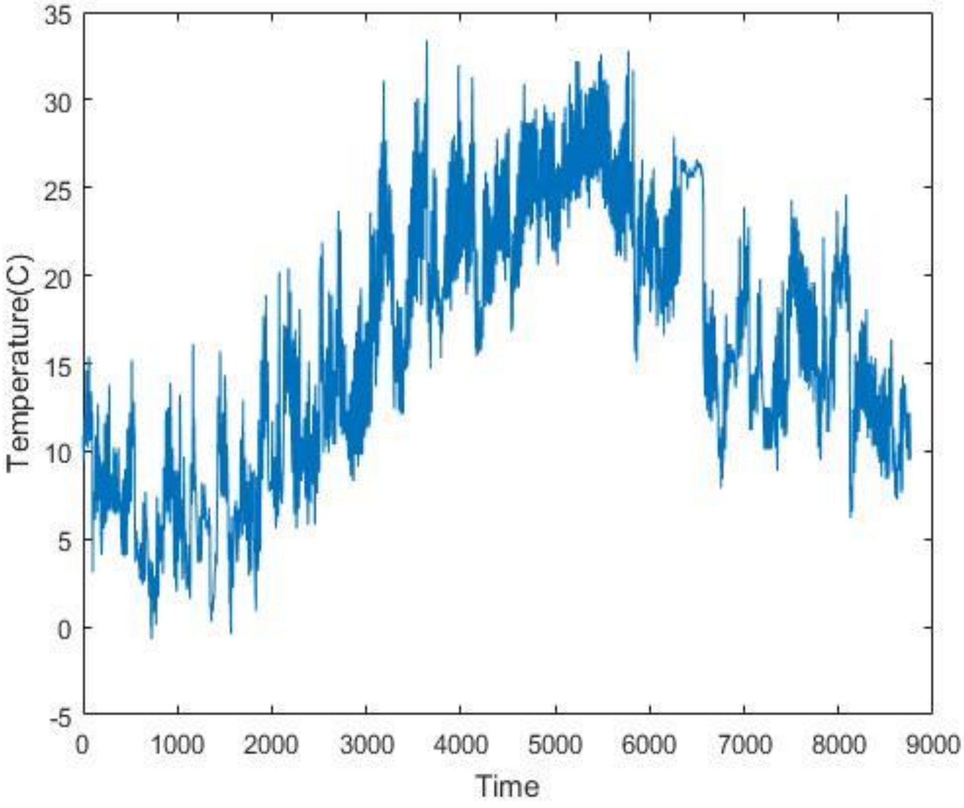


Figure 2.4 : Hourly average of temperature.

The temperature of the environment is important to calculate the PV temperature. Because, the efficiency of panels is depended to the temperature.

2.3 Calculation Method

In this section calculation method will be described for each system.

2.3.1 Calculation for solar sytem

In the solar system, firstly the incidence angle must be obtained. The incidence angle can be calculated from the equation (1.11). We have to compute incidence angle for each hour. In this case, we consider panel tilt 31 which is 10 degrees lower than local latitude. By multiplying the result of this equation to solar irradiances the amount of solar irradiance which reaches to PV panel can be obtained in one hour. After this step, we have to compute the solar panels temperature. As it has been mentioned in previouse pages (according to the equation (1.21)) the operating cell temperature of photovoltaic moduls directly affect the performans of PV system. So we have to estimate modules operating temperature. For this purpose we use an equation which has presented by (Muzathik, 2014).

$$T_{\mathrm{mod}ule}(\circ C) = 0.943 \times T_{ambient} + 0.0195 \times Irradiance - 1.528 \times WindSpeed + 0.3529 \quad (2.1)$$

From equation (1.21) the efficiency of mudule can be obtained :

$$\eta_T = 1 + (\alpha + \beta)\Delta T = 1 + (\alpha + \beta)(T - 25) \quad (2.2)$$

Then we can compute the efficiency for each hour. After that by multiplying efficiency to solar iraadiances the amount of power generation can be obtained

$$P_{solar} = irradiance \times \cos\theta \times \eta_T \quad (2.3)$$

2.3.2 Calculation for wind system

In the wind system at first, we have configured our wind turbine characteristic. We have chosen Enercon E-44 900KW wind turbine for this purpose. Because for generation power at this output power, a license from the government is not needed. This turbine operates at 5m/s cut-in speed and 25m/s cut-off speed.

The characteristic of wind speed and output power curve is shown in Figure 2.5.

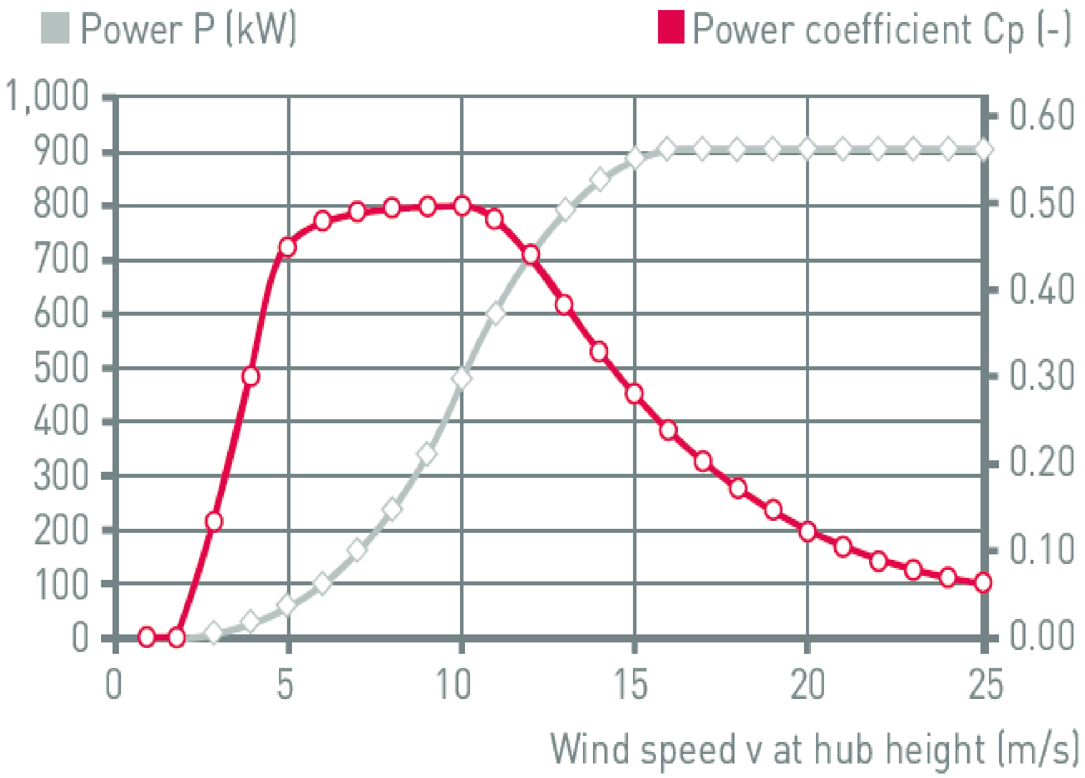


Figure 2.5 : The charactersictic of wind speed and output power curve

We have approximate this curve by Matlab and extarcted the relation between wind speed and out put power according to Figure 2.5 .

$$P_{wind} = \frac{a + cv + ev^2 + gv^3 + jv^4}{1 + bv + dv^2 + fv^3 + kv^4} \tag{2.4}$$

And the coefficients are :

a=2.284706792
b=-0.19393455
c=-4.48401902
d=0.015823826
e=2.223591227
f=-0.00060624
g=-0.16978386
j=1.17875e-05
k=0.006247327

The curve of this equation is shown in the Figure 2.6. Also, it is illustrated the same values of wind turbine characteristic.

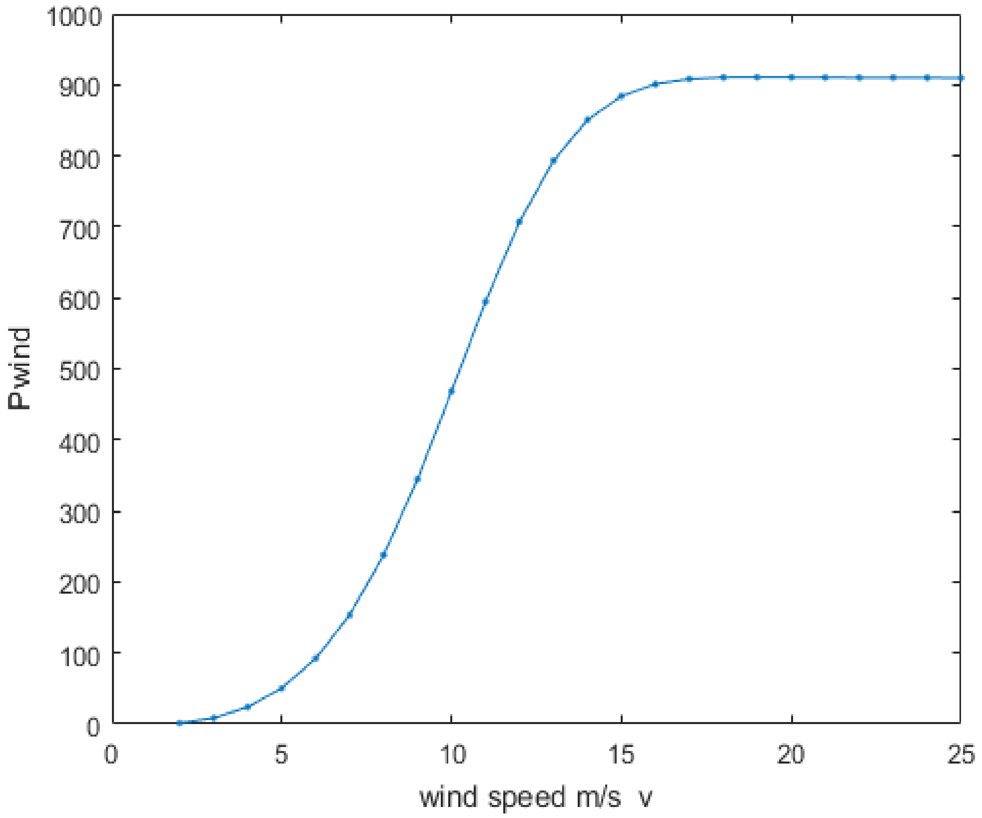


Figure 2.6 : Curve of approximated relation.

In the wind power generation we have chosen Enercon E-44 wind turbine which has 900 kW nominal output power and 45 meters height. For computing wind speed the Hellman equation is used in a way that the Hellman exponent is obtained by using the wind speed at given heights at 2 meters and 10 meters . Then it is calculated in 45 meter which is the height of the turbine's hub. At the end, we have used the calculated wind speed at 45 meters as an input of equation (2.4) so we can extract the generation of the wind system in each houre.

At the last step, we have computed the daily energy generation of each system. By adding solar and wind system outputs we obtained the total energy generation of the hybrid system for each day.

Then we have computed the solar system proportion and wind system proportion in percent for each day. By calculating the daily average proportion of wind system and solar system and multiplying annual average of these percent to the output power of each system the optimal power generation capacity is obtained and so the nominal established power generation is 900 kW.

3. RESULTS

In this chapter we will demonstrate the result of the our caculation .

3.1 Solar System

As it has been described in the last chapter firstly we have calculated the solar incidence angle. The variason of the incidiance angle is shown in below Figure 3.1.

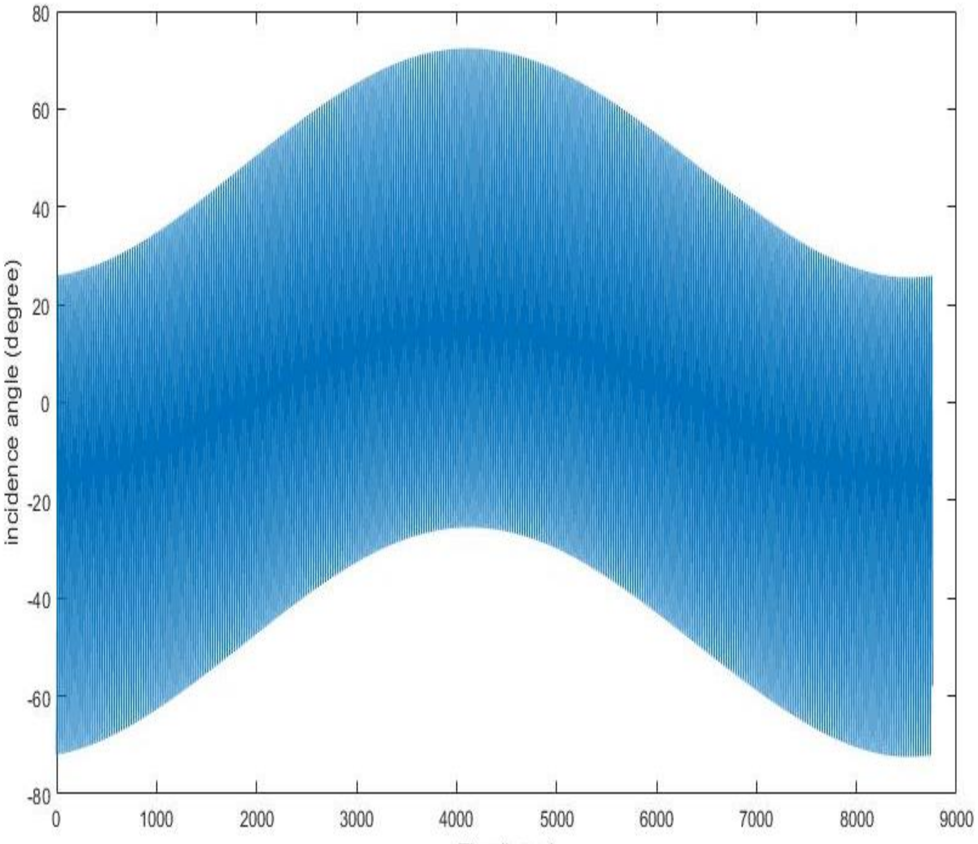


Figure 3.1 : Hourly variation of incidince angle.

We must use the cos of this angle which is shown in below. This is the solar incidence angle which is the angle between the sun's irradiance and the normal on a panel. This is used for calculation amount of solar irradiances reaching the pv panel during sun radiation in daylight. The cos of incidince angle is shown in Figure 3.2.

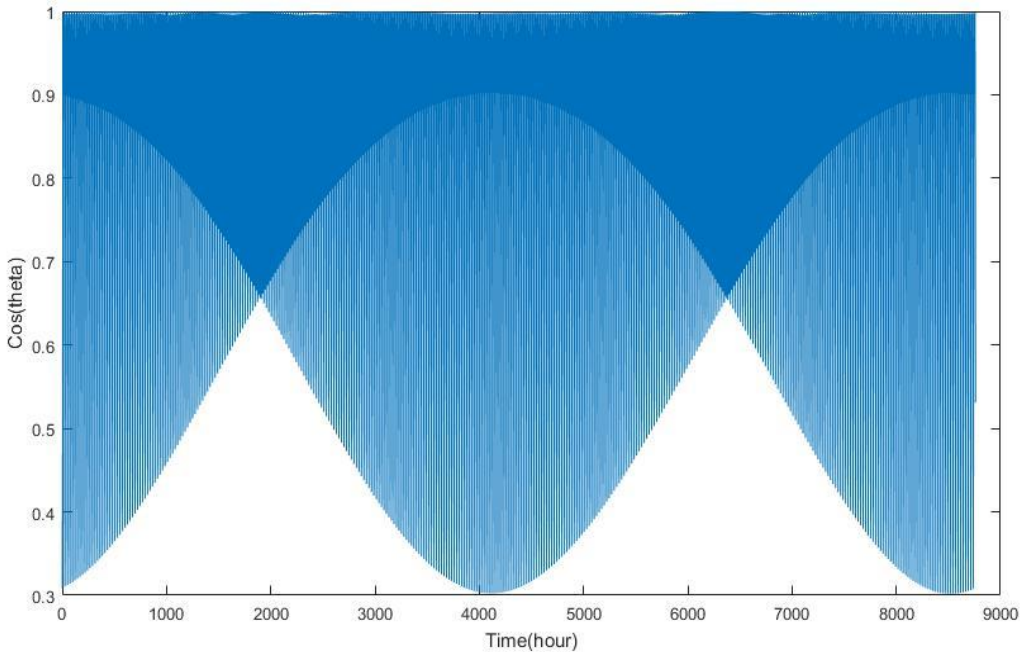


Figure 3.2 : Hourly changes of $\cos(\theta)$.

By multiplying cos of incidince angle to the sun irradiance the amont solar iradiance which reches to PV can be obtained the results of this multiplication is illastrated in Figure 3.3.

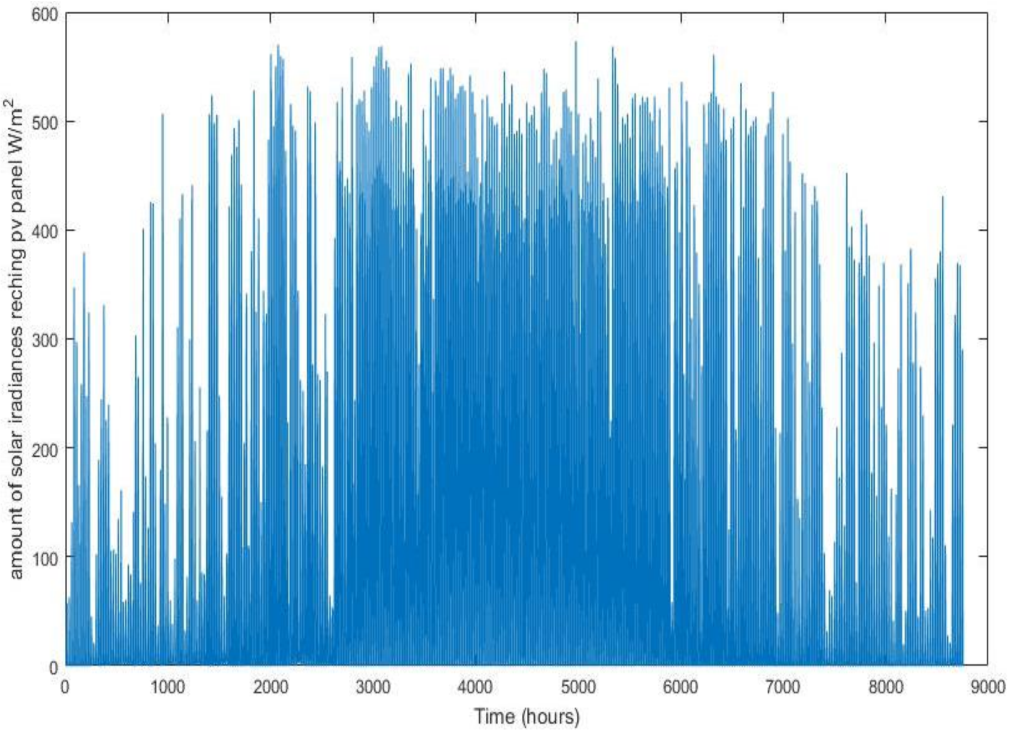


Figure 3.3 : The amount of solar irradiance which reches to PV.

In this step we have to estimate the PV temperature. We have used the equation (2.1) for this goal. The input data for this equation is wind speed at 2 meters height and the solar irradiance and the ambient temperature. The result is shown in Figure 3.4.

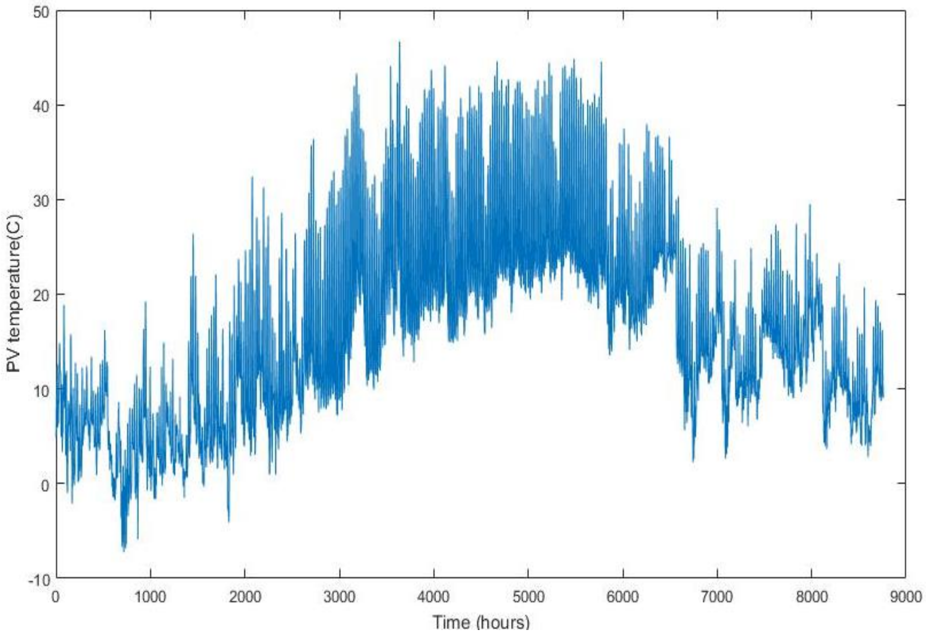


Figure 3.4 : Hourly variation of PV temperature.

According to the Figure 1.22, Figure 1.23, Figure 1.24 and equation (1.21) we have calculated the output power of one panel in 1 meter square. The result for Monocrystalline is shown in Figure 3.5.

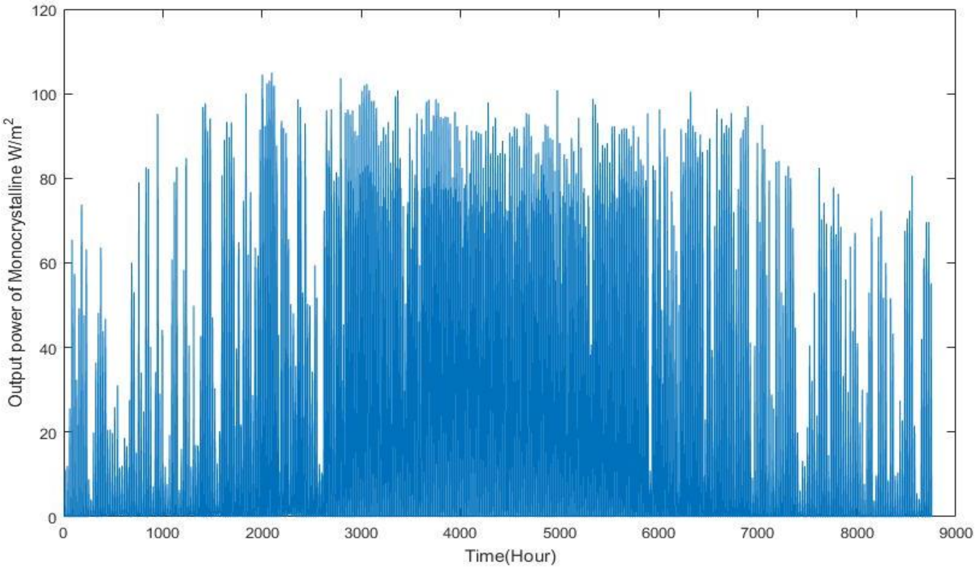


Figure 3.5 : Hourly output power of Monocrystalline.

The results for Polycrystalline is shown in Figure 3.6.

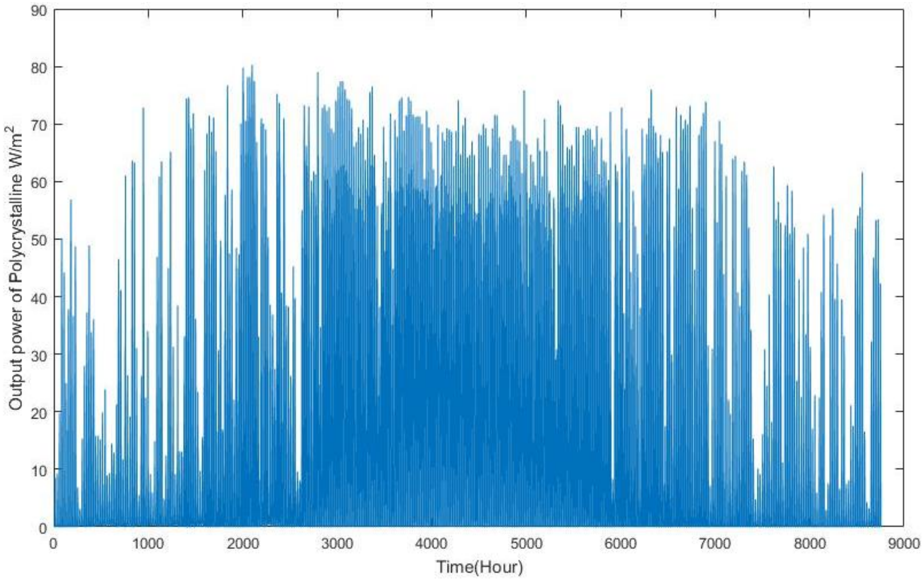


Figure 3.6 : Hourly output power of Polycrystalline.

The results for Multijuction is shown in Figure 3.7.

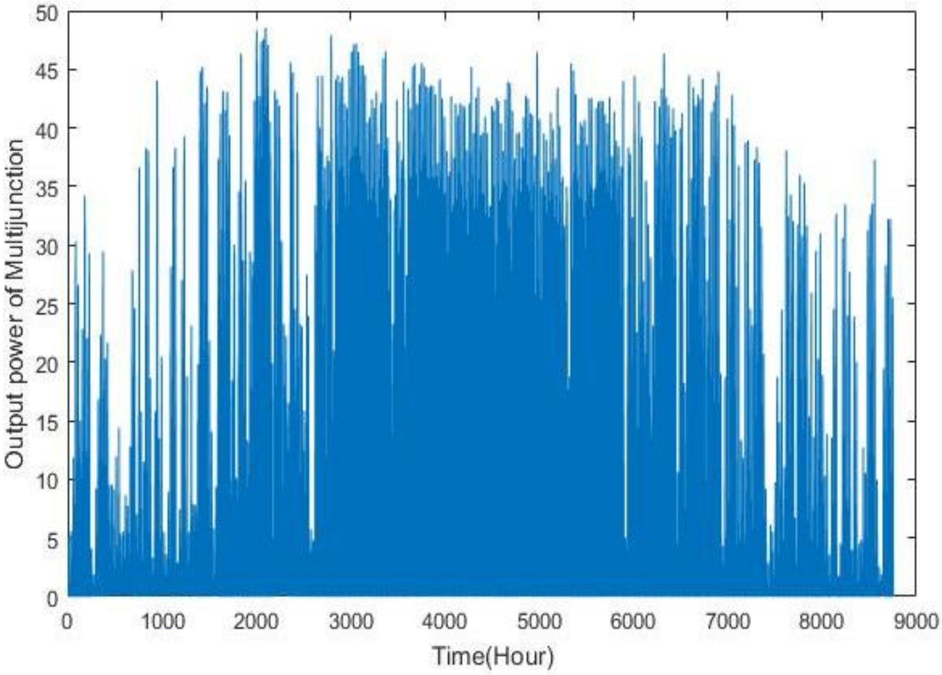


Figure 3.7 : Hourly output power of Multijunction.

By considering our nominal output power 900 kw we have to calculate number of panels. We have used the electrical data of PV panel for each type and we have calculated the the total panel surface by dividing this surface to each panel area the total number of panels can be obtained from this way.

For Monocrystalline :

$$\frac{900\,kW}{184W/m^2} = 4891.3m^2 \Rightarrow \frac{4891.3m^2}{1.25m^2} = 3913.04 \cong 3913 \; \textit{number of panels} \quad (3.1)$$

$$3913 \times 1.25m^2 = 4891.25m^2 \; \textit{total panel area} \quad (3.2)$$

$$3913 \times 1.25m^2 = 4891.25m^2 \; \textit{total panel area} \quad (3.3)$$

For Poly-crystalline :

$$\frac{900\,kW}{142W/m^2} = 6338.02m^2 \Rightarrow \frac{6338.02m^2}{1.9m^2} = 3335.8 \cong 3336 \; \textit{number of panels} \quad (3.4)$$

$$3335.8 \times 1.9m^2 = 6338.4m^2 \, \textit{total panel area} \quad (3.5)$$

For Multijunction :

$$\frac{900\,kW}{85W/m^2} = 10588.23m^2 \Rightarrow \frac{4891.3m^2}{1.7m^2} = 6228.37 \cong 6228 \; \textit{number of panels} \quad (3.6)$$

$$6228 \times 1.7m^2 = 10587.6m^2 \, \textit{total panel area} \quad (3.7)$$

By multiplying these areas to the hourly output of each type of panel the hourly power genertion of solar system can be obtained in one year. The results for Monocrystalline is shown in Figure 3.8.

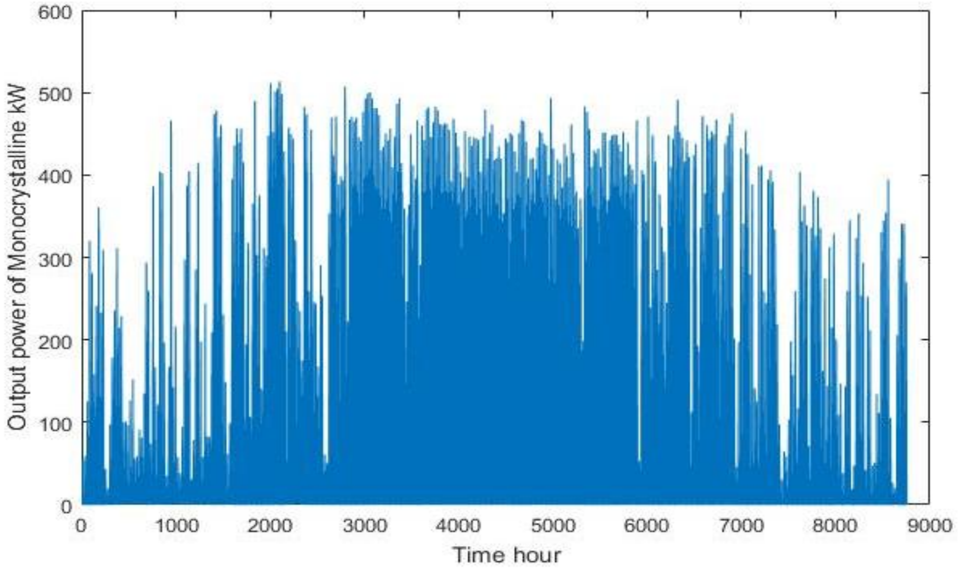


Figure 3.8 : Output power of Monocrystalline.

The total annual power generation in this case is: 888.536975MWh. The results for Polycrystalline is shown in Figure 3.9.

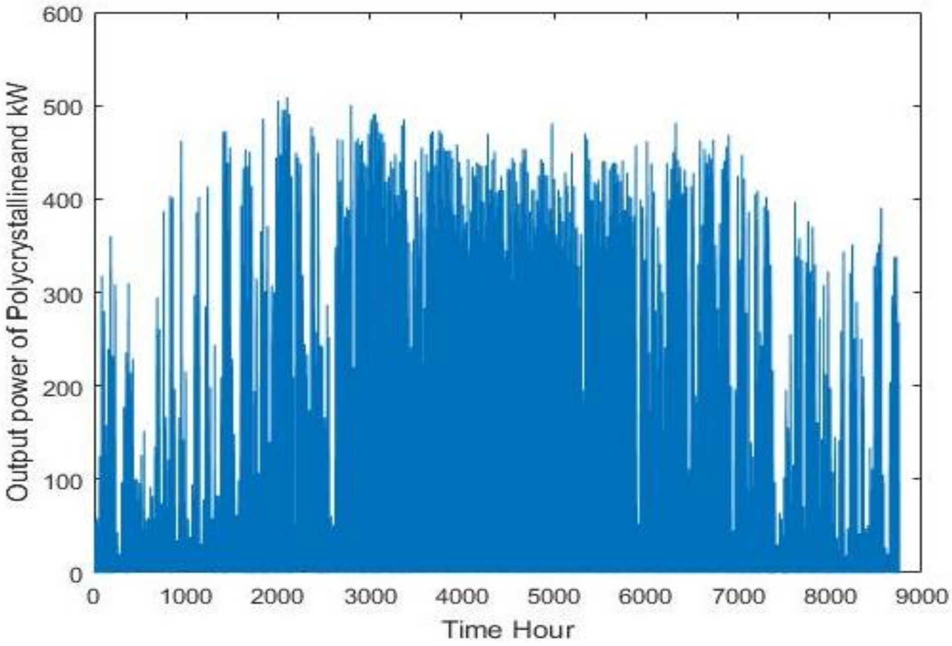


Figure 3.9 : Output power of Polycrystalline.

The total annual power generation in this case is: 875.031736 MWh. The results for Multijunction is shown in Figure 3.10.

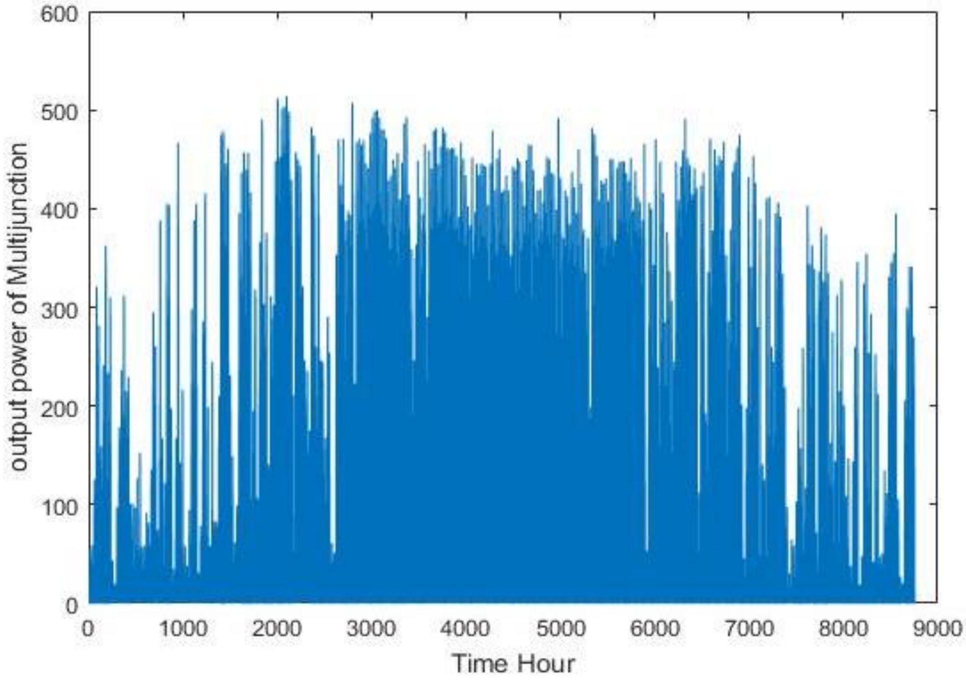


Figure 3.10 : Output power of Multijunction.

The total annual power generation in this case is: 888.256499 MWh.

3.2 Wind System

For calculating the output power of wind system firstly we must estimate the wind speed at wind turbine's height which is 45 meter. The wind speed at 2 meters and 10 meters is known. In each hour so by using Hellman equation which is equation (1.10) the wind speed at 45-meter height can be obtained. In the figure below the result of this equation is illustrated in Figure 3.11.

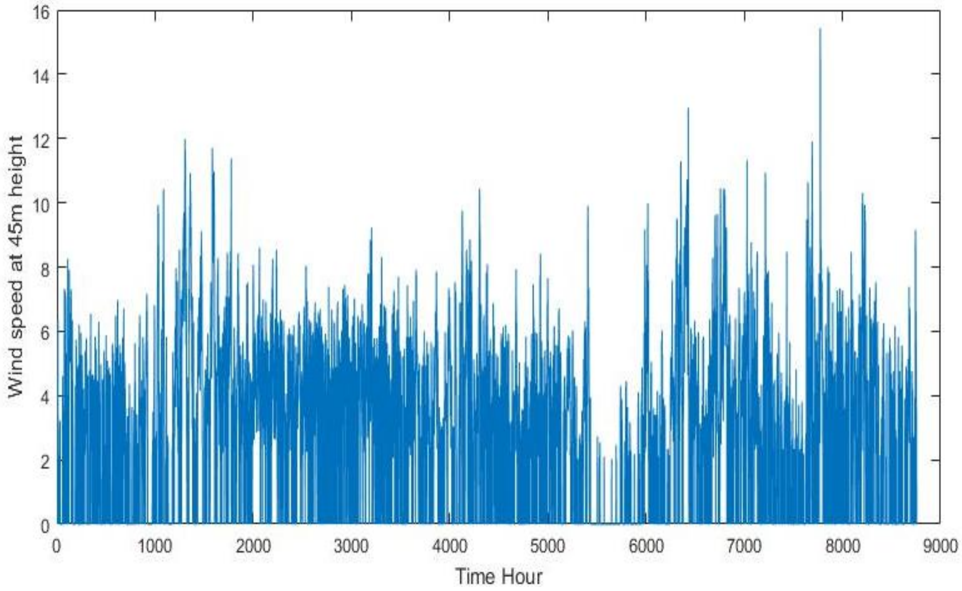


Figure 3.11 : Estimated wind speed at 45 m height.

Then we have used the results of this estimation as an input of equation (2.4) the results are shown in below Figure 3.12.

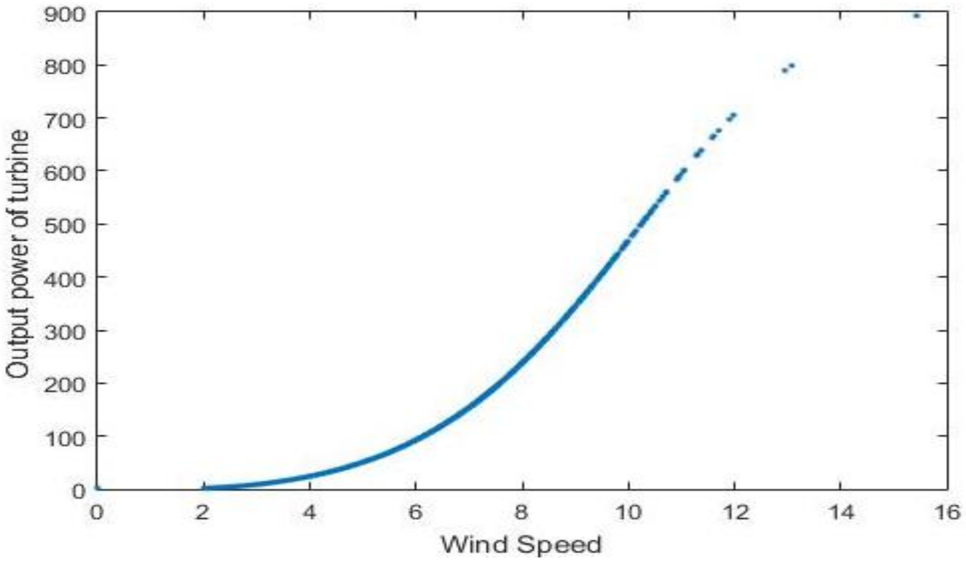


Figure 3.12 : Power generated by wind speed at 45 m height.

The hourly power genertion of wind sytem is demonstrated in Figure 3.13.

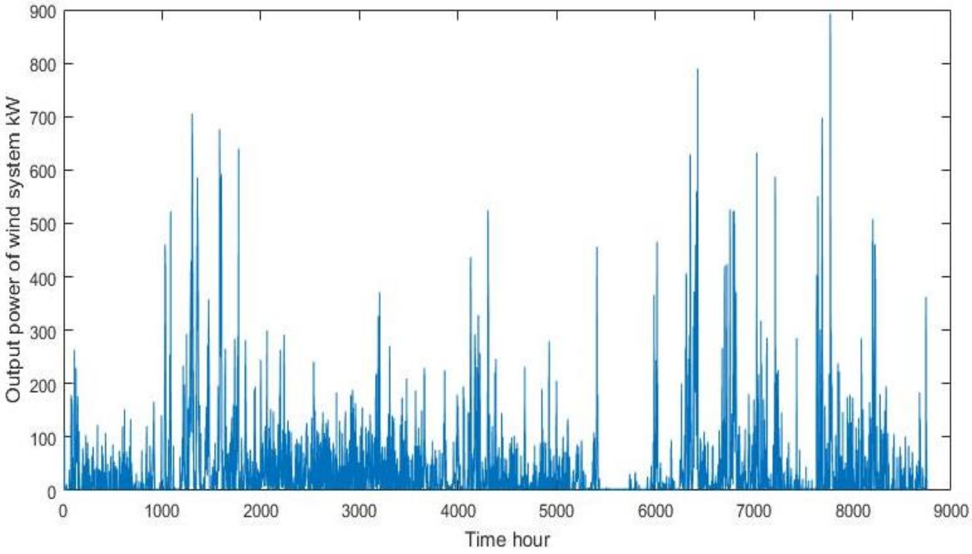


Figure 3.13 : Hourly wind power generation.

In this chapter, we have seen the results of the equation under several conditions.

In next chapter will describe and show the combination of these results in the hybrid system. The total wind system energy genertion is 345.299822 MWh.

4. BEHAVIOUR AND THE OUTPUT OF THE HYBRID SYSTEM

In this case firstly we have caculated the daily generation of system then, we have obtained proportion for each system at the last step we have calculated capacity factor. The result of wind energy generation is shown in Figure 4.1.

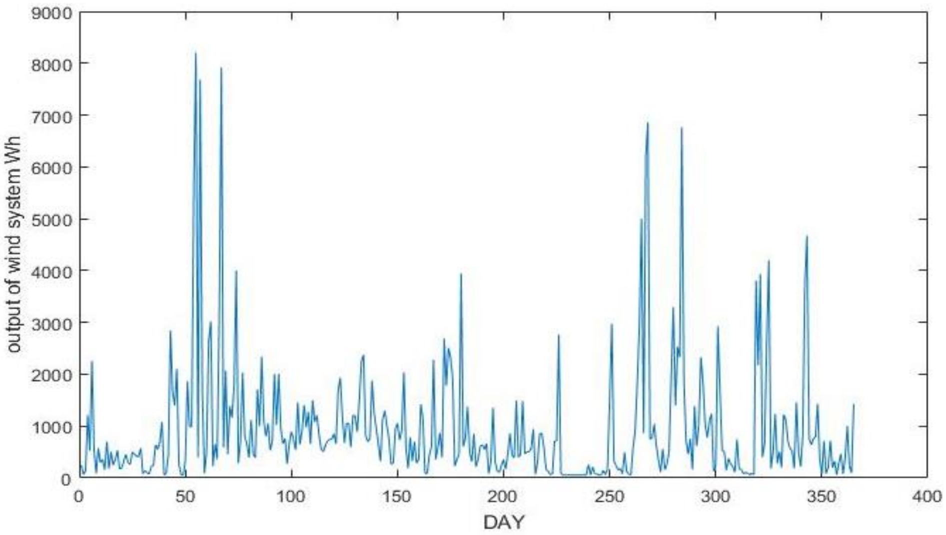


Figure 4.1 : Daily generation of wind system.

After that we must calculate the daily generation of solar system. The daily generation of solar system with Monocrystalline type PV is shown in Figure 4.2.

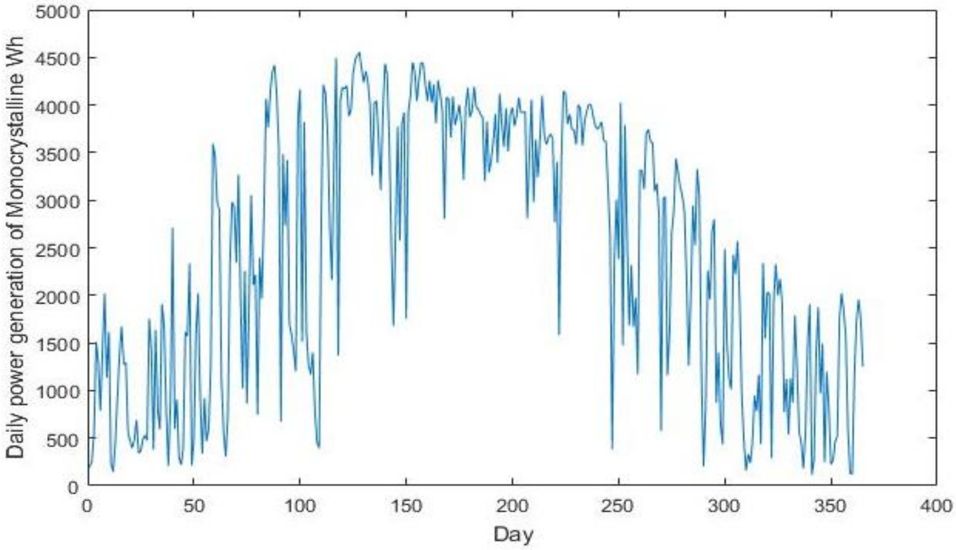


Figure 4.2 : Daily power generation of Monocrystalline.

And we have given the seasonal power generation for each system in Table 4.1.

Table 4.1 : Seasonal power generation for wind and solar system.

Season / System	Wind (MWh)	Solar (MWh)
Spring	90.6765	315.87262
Summer	65.90944	325.2744
Fall	97.75657	138.78151
Winter	91.96217	108.32295

Both of these generation in one figure is illustrated in Figure 4.3. We can see the complementary feature of hybrid system in the Figure 4.3.

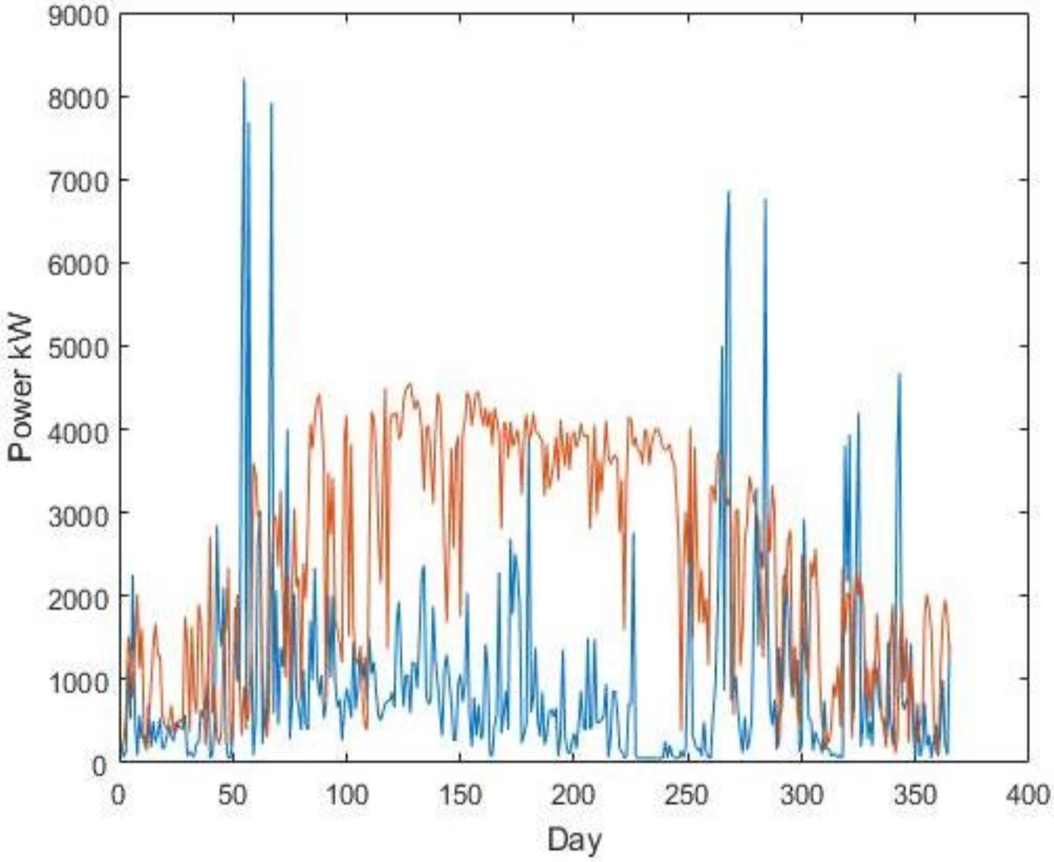


Figure 4.3 : Solar and wind daily generation.

In the next step we are going to calculate the proportion of wind system and solar system in daily hybrid generation.

4.1 Proportion Calculation

By adding the solar energy and wind energy we have more susutainable power generation , which was our puepose in this hybrid system. Then it is obvious that the maximum and minumum power generation of solar system and wind system maches each other in the Figure 4.4.

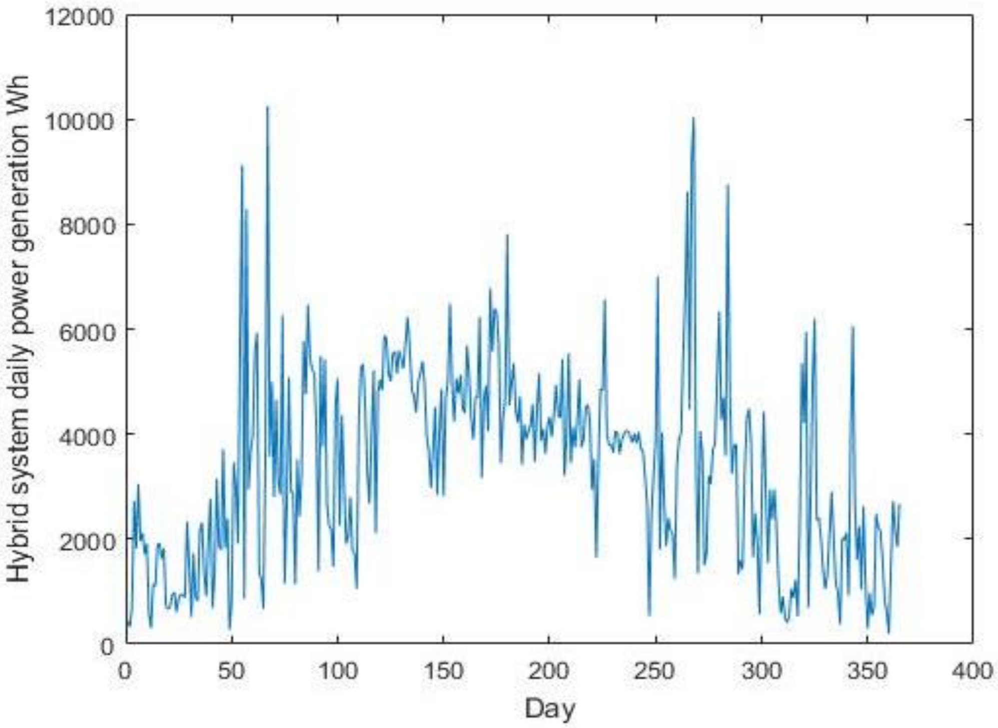


Figure 4.4 : Hybrid system output.

By adding solar and wind system outputs we obtained the total energy generation of the hybrid system for each day, then we have to compute the solar system proportion and wind system proportion in percent for each day. By calculating the daily average proportion of wind system and solar system and multiplying annual average of these percent to the output power of each system the optimal power generation capacity is obtained. The results of average is :

- Solar Monocrystalline proportion : 72.02% ≅ 72%
- Wind system proportion : 27.98% ≅ 28%

The aim of this calculation is to obtain the most suitable propotion for both wind system and solar sytem to generate power at 900 kW.

The proportional daily solar power genration for Monocrystalline is shown in Figure 4.5.

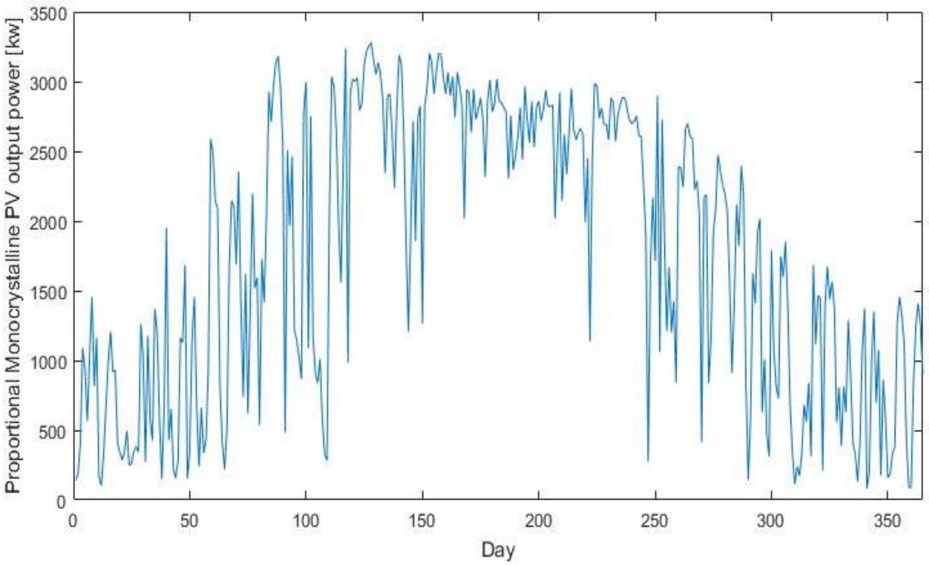


Figure 4.5 : Proportional solar power generation.

Proportional daily wind power genration during one year is illustrated in Figure 4.6.

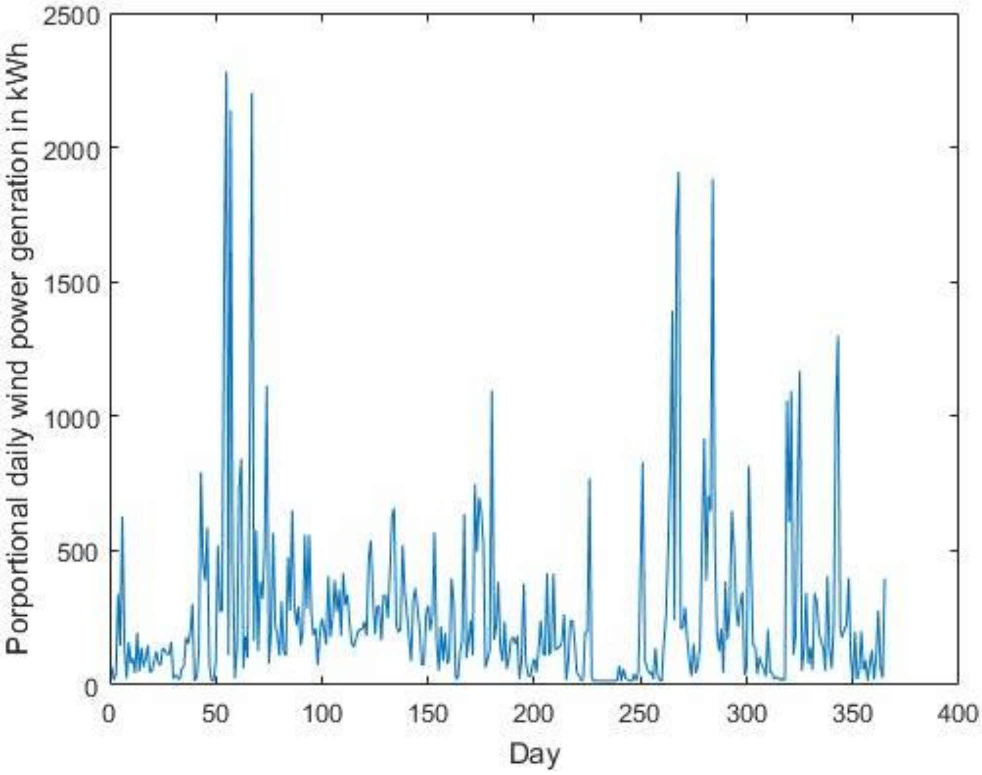


Figure 4.6 : Porportional daily wind power genration in kWh.

It is obvious that the wind power generation has decreased dramatically.

At the end we can see the proportional hybrid system output in the Figure 4.7.

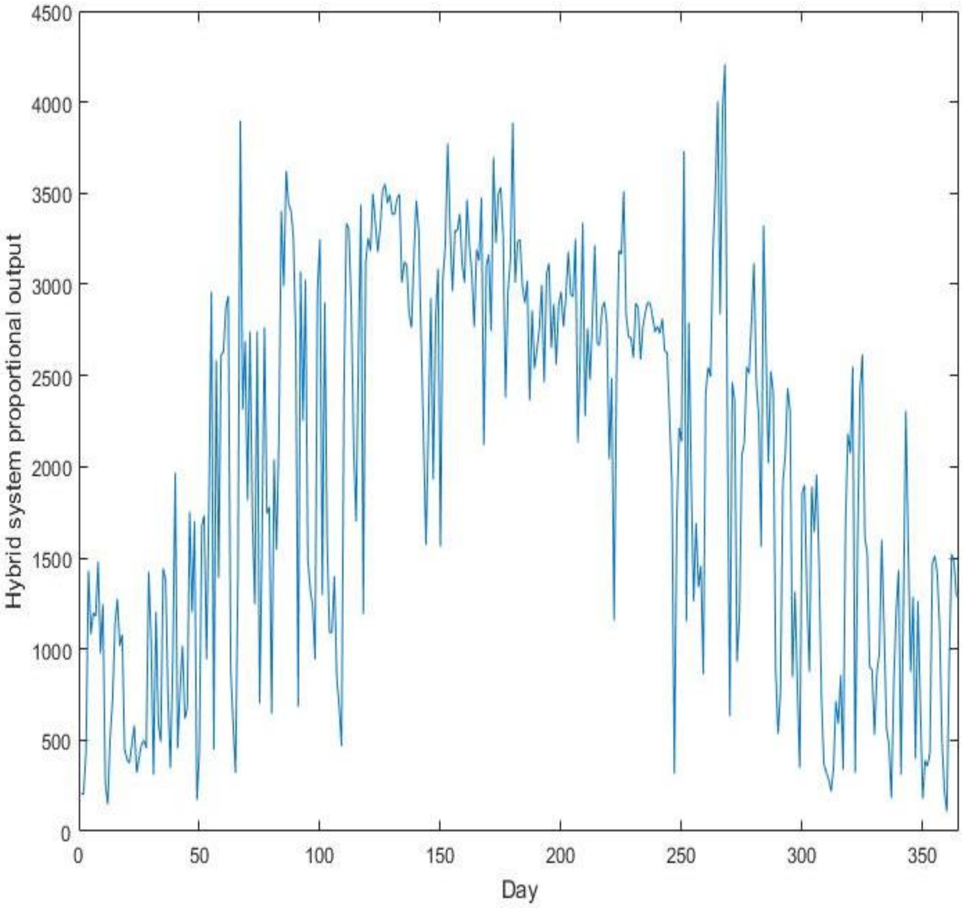


Figure 4.7 : Proportional hybrid system daily power generation kWh.

Total porpotional hybrid system power generation is : 736.430572 MWh. In the same way we have calculated the proportion of Polycrystalline and Multijunction, which are given in the Table 4.2. As it can be seen there is no dramatic diffrence among these values.

Table 4.2 : Proportion of energy generation and hybrid system output.

Type of PV	Proportion	Proportion of wind	Hybrid system output
Monocrystalline	72.17%	27.83%	736.43057 MWh
Polycrystalline	72.02%	27.98%	726.7068 MWh
Multijunction	72.18%	27.82%	736.22863 MWh

In the next step we have calculated each sytems capacity factors.

4.2 Calculation of Capacity Factor For Wind System And Solar ystem

In this case, we are going to calculate the capacity factors of each system.The aim of this calculation is to understand that how much is these system is suitable for this location.

4.2.1 Calculation of the capacity factor for the wind system

You can see the relation for calculating the capacity factor for wind system below:

$$\frac{output\ power\ of\ the\ wind\ system}{365(days)\times 24\left(\frac{hours}{day}\right)\times 900\ kW} = \frac{345.299822MWh}{7884MWh} = 0.04379 = 4.379\% \qquad (4.1)$$

4.2.2 Calculation of the capacity factor for the solar system

You can see the relation for calculating the capacity factor for solar (mono-crystalline) system below.

$$\frac{output\ power\ of\ the\ wind\ system}{365(days)\times 24\left(\frac{hours}{day}\right)\times 900\ kW} = \frac{888.5369MWh}{7884MWh} = 0.1127 = 11.27\% \qquad (4.2)$$

5. CONCLUSION

In this study, we have analyzed the behavior of the hybrid wind-solar power plant for ITU Ayazaga campus. We have chosen 900 kW system because this kind of system with this capacity does not need any license from the government. We have calculated the output power of wind system and solar system, then select the proportion for each system to keep output power at 900 kW.

It can be said that it is generally appropriate to use 72% photovoltaic and 28% wind components for such a wind-solar hybrid system since the rates obtained from energy production and energy production values are very close to each other. This means about 650 kW solar and 250 kW wind as installed power.

In the selection of the photovoltaic cell type, one can favor one of the two because mono-crystalline or multijunction thin films produce almost the same amount, but the panel area will affect the decision of the area, price and availability to cover the photovoltaic field. If you look at the photovoltaic battery used in this study, the mono-crystal pylon area of 230 W power is 1.25 m^2, the poly-crystal pylon area is 1.9 m^2 at the 270 W power and the multijunction thin film area at 145 W power is 1.7 m^2.

According to the results, we have calculated the capacity factor for the wind system and solar system. And results demonstrates the wind system is not suitable for this system because of the low capacity factor.

Although the use of wind-solar hybrid power plant provides more homogeneous electricity generation during the year, it is clear that solar energy for ITU Ayazağa campus is a priority. Therefore, the establishment of solar panels on the roofs of buildings within the campus can be a priority. Since the floor problem is highlighted in roof installations, it may be advisable to use mono-crystal, which is the highest type of panel to provide the highest installed power.

REFERENCES

Akella, A. K., Saini, R. P., & Sharma, M. P. (2009). Social, economical and environmental impacts of renewable energy systems. *Renewable Energy*, 34(2), 390-396

Boyle, G. (1996). *Renewable Energy: Power for a Sustainable future* (Vol. 1996). Oxford University Press, USA.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., ... & von Stechow, C. (2011). IPCC special report on *renewable energy sources and climate change mitigation. Prepared By Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK.

Ekren, O., Ekren, B. Y., & Ozerdem, B. (2009). Break-even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage–a case study. *Applied Energy*, 86(7), 1043-1054.

Elhadidy, M. A., & Shaahid, S. M. (2004). Promoting applications of hybrid (wind+ photovoltaic+ diesel+ battery) power systems in hot regions. *Renewable Energy*, 29(4), 517-528

Halasa, G., & Asumadu, J. A. (2009, May). Wind-solar hybrid electrical power production to support national grid: Case study-Jordan. *In Power Electronics and Motion Control Conference*, 2009. IPEMC'09. IEEE 6th International (pp. 903-909). IEEE.

Ingole, A. S., & Rakhonde, B. S. (2015). Hybrid power generation system using wind energy and solar energy. *International Journal of Scientific and Research Publications*, 5(3), 1-4.

Kalogirou, S. A. (2009). *Solar energy engineering: processes and systems*. Academic Press.

Mahmoudi, H., Abdul-Wahab, S. A., Goosen, M. F. A., Sablani, S. S., Perret, J., Ouagued, A., & Spahis, N. (2008). Weather data and analysis of hybrid photovoltaic–wind power generation systems adapted to a seawater greenhouse desalination unit designed for arid coastal countries. *Desalination*, 222(1-3), 119-127.

Moreno, B., & Lopez, A. J. (2008). The effect of renewable energy on employment. The case of Asturias (Spain). *Renewable and Sustainable Energy Reviews*, 12(3), 732-751.

Muralikrishna, M., & Lakshminarayana, V. (2008). Hybrid (solar and wind) energy systems for rural electrification. *ARPN Journal of Engineering and Applied Sciences*, 3(5), 50-58.

Muzathik, A. M. (2014). Photovoltaic modules operating temperature estimation using a simple correlation. *International Journal of Energy Engineering*, 4(4), 151.

Shanker, S., & Sharma B, S. (2012). Optimization of Solar and Wind Hybrid System. *International Journal of Science and Research*, 104-109**.**

Subrahmanyam, J. B. V., Alluvada, P., Bhanupriya, K., & Shashidhar, C. (2012a). Renewable Energy Systems: Development and Perspectives of a Hybrid Solar-Wind System. *Engineering, Technology & Applied Science Research*, 2(1), pp-177.

Subrahmanyam, J. B. V., Sahoo, P. K., & Reddy, M. (2012b). Local PV-Wind hybrid systems development for supplying electricity to industry. *Acta Electrotechnica*, 53(1), 10-15.

Tina, G., Gagliano, S., & Raiti, S. (2006). Hybrid solar/wind power system probabilistic modelling for long-term performance assessment. *Solar energy*, 80(5), 578-588.

Tiwari, G. N., & Mishra, R. K. (2012). *Advanced renewable energy sources. Royal Society of Chemistry.*

Wei, M., Patadia, S., & Kammen, D. M. (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US. *Energy policy*, 38(2), 919-931.

Wiser, R. (2012). 2010 Wind technologies market report.

Yang, H., Wei, Z., & Chengzhi, L. (2009). Optimal design and techno-economic analysis of a hybrid solar–wind power generation system. *Applied Energy*, 86(2), 163-169.

Pitstone Windmill. (2015). In *Wikipedia*. Date retrieved: 07.12.2016, adress: http://en.wikipedia.org/wiki/Pitstone_Windmill

The End Of Fossil Fuels. (2014). In *ecotricity.* Date retrieved: 07.08.2016, adress: https://www.ecotricity.co.uk/our-green-energy/energy-independence/the-end-of-fossil-fuels

US Natural gas wellhead price. (2013). In *Energy Information Administartion.* Date retrieved: 07.09.2016, adress: https://www.eia.gov/dnav/ng/hist/n9190us3m.htm

Url-1 <*http:// www.enercon.de/en/products/ep-1/e-44/*>, date retrieved 29.06.2016.

Url-2 <*http://www.google.com.tr/maps* >, date retrieved 10.03.2017.

CURRICULUM VITAE

Name Surname: Nima Jafarzadeh

Place and Date of Birth: Tabriz – 28.05.1989

E-Mail: nima_jafarzadeh@yahoo.com

EDUCATION:

B.Sc.: 2012, Islamic Azad University of Tabriz, Engineering Faculty, Electrical Engineering.