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An Analytical Study for Establishment of Wind Farms in Palestine to Reach the Optimum Electrical Energy

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Dedication

To my parents and

my sisters Eman and Rawan …

To my wife Zahraa

Acknowledgment

I have taken efforts in this research which really would have been impossible without the indebted support and help of many individuals. I would like to extend my sincere thanks to all of them.

Beginning with my thesis supervisor Prof. Dr. Mohammed T. Hussein, for his guidance and constant supervision as well as for providing necessary information and continuous follow-up of this research.

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My thanks and appreciations also go to the Engineers and Consultants in Authority of Energy, who have helped me out with their abilities.

I would also like to express my gratitude towards my parents for their co-operation, prayers and encouragement all my life helping me going forward especially in completion of this research.

ملخص البحث

في الفترة الأخيرة أصبحت الطاقة المتجددة تحظى بقدر كبير من الأهمية، خاصة بعد العديد من المشاكل التي أحدثها التلوث بالبيئة، بالإضافة إلى قلة الموارد ونقصها وقابليتها للنفاذ بسبب الزيادة المتلاحقة على الاستهلاك للمصادر غير المتجددة في شتى مجالات الحياة.

ومع الوضع الحرج والحصار التي تعيشه فلسطين وخاصة قطاع غزة في الفترة الأخيرة وحاجة المجتمع إلى مصدر بديل للطاقة بدلاً من مصادر الطاقة التقليدية المتوفرة، حيث أصبح الأمر ملحاً وخصوصاً مع استمرار انقطاع التيار الكهربائي وندرة المحروقات حيث أصبحت هناك حاجة ماسة لدراسة مصادر الطاقة المتجددة في فلسطين.

و تهدف هذه الدراسة البحثية إلى التعرف على مدى جدوى استخدام طاقة الرياح في فلسطين من خلال تحليل بيانات سرعة الرياح والاعتماد على الدوال الاحتمالية المتطورة التي تخدم هذا النوع من الدراسات، وحساب كمية الطاقة والقدرة التي يمكن أن تنتج لكل 1 متر مربع خلال العام، حساب منحنى الطاقة الفعلي باستخدام منحنى Weibull، حساب تكلفة الانتاج لكل 1 كيلو واط من الطاقة، والقدرة على حساب فترة استرداد رأس المال لأي مشروع يمكن انشاؤه.

Abstract

On the last decade, crisis problem of electrical energy has been considered as one of the big problems around the world. In particular manner, Palestine suffers from the lack of traditional resources, Moreover, it witnesses an increase in consecutive consumption of non-renewable sources in various fields of life.

Among the critical situation, the siege imposed, and the needs to an alternative source of energy instead of traditional energy, where this matter became urgency, especially with the continued interruption of electric power as well as fuel.

The goal of this research study is the assessment of wind energy production in the Palestine by analyzing wind data, using expert probability function used in this field of research, calculating the amount of Power and Energy that can be produced from each one meter square during the year, calculating the actual energy curve through Weibull curve, calculating the cost of production per one kilowatt of energy and the ability to calculate the Economical payback period for any project if built in Palestine.

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CHAPTER 1

INTRODUCTION

RENEWABLE ENERGY

Renewable energy uses energy sources that are continually replenished by nature: the sun, the wind, water, the Earth's heat, and plants. Renewable energy technologies turn these fuels into usable forms of energy most often electricity, but also heat, chemicals, or mechanical power [1]. Renewable energy sources can be difficult to control. They are based on weather related phenomena, such as wind, sun and rain. To adjust energy production to consumption, it can therefore be necessary to store energy for short or long periods of time [2]. The voluntary renewable energy market has grown considerably since its inception in the 1990s. In 2009, more than 30 million MWh of renewable energy were sold in the voluntary market, a nearly four-fold increase compared to 2005 and almost equal to the amount of new renewables required to meet 2009 state renewable portfolio standards [3].
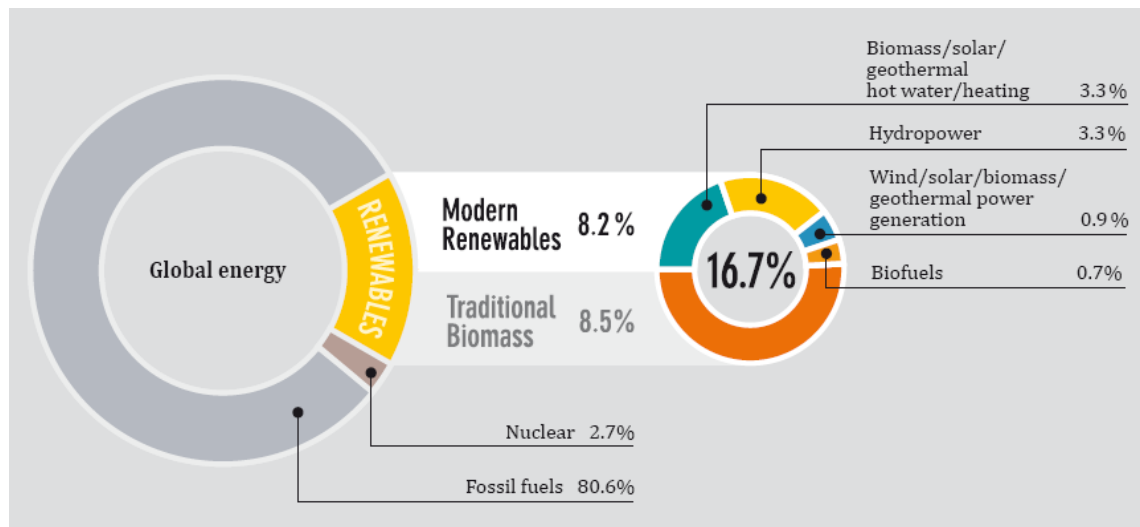
Figure (1-1) Renewable Energy Share of Global Final Energy Consumption, 2010.
(Source: Renewable 2012 Global Status Report).

Figure (1-1) shows Renewable energy in 2010 as it supplied an estimated 16.7% of global energy consumption. Of this total, an estimated 8.2% came from modern renewable energy including hydropower, wind, solar, geothermal, biofuels, and modern biomass.

Traditional biomass, accounted for 8.5% of total energy, Hydropower supplied about 3.3% of global energy consumption, All other modern renewables provide 4.9% of energy consumption.

1.1   Biomass Energy

The term "biomass" refers to organic matter that has stored energy through the process of photosynthesis. It exists in one form as plants and may be transferred through the food chain to animals' bodies and their wastes, all of which can be converted for everyday human use through processes such as combustion, which releases the carbon dioxide stored in the plant material. Many of the biomass fuels used today come in the form of wood products, dried vegetation, crop residues, and aquatic plants. Biomass has become one of the most commonly used renewable sources of energy in the last two decades, second only to hydropower in the generation of electricity. It is such a widely utilized source of energy, probably due to its low cost and indigenous nature, that it accounts for almost 15% of the world's total energy supply and as much as 35% in developing countries, mostly for cooking and heating.
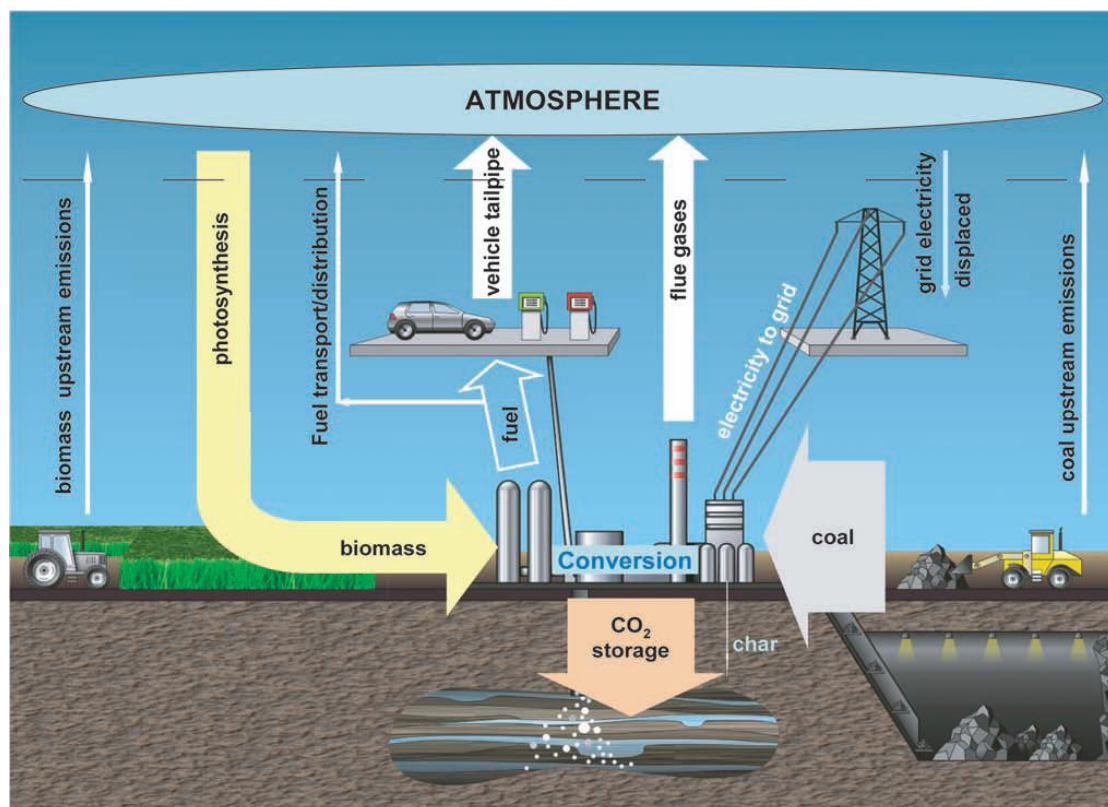
Figure (1-2) Biomass energy cycle.
(Source: Larson et al., 2010).

Carbon flows for conversion of coal and biomass to liquid fuels and electricity. When biomass is approximately 30% of the feedstock input (on a higher heating value basis) [4], Biomass is one of the most plentiful and well-utilized sources of renewable energy in the world. Broadly speaking, it is organic material produced by the photosynthesis of light. The chemical material (organic compounds of carbons) is stored and can then be used to generate energy. The most common biomass used for energy is wood from trees. Wood has been used by humans for producing energy for heating and cooking for a very long time [5], biomass energy cycle shown in figure (1-2).

1.2   Geothermal energy

The word geothermal comes from the Greek words *geo* (Earth) and *therme* (heat). Geothermal energy is heat from within the Earth. Geothermal energy is generated in the Earth's core, almost 4,000 miles beneath the Earth's surface. The double-layered core is made up of very hot magma (melted rock) surrounding a solid iron center. Very high temperatures are continuously produced inside the Earth by the slow decay of radioactive particles. This process is natural in all rocks. Surrounding the outer core is the mantle, which is about 1,800 miles thick and made of magma and rock. The outermost layer of the Earth, the land that forms the continents and ocean floors, is called the crust. The crust is three to five miles thick under the oceans and 15 to 35 miles thick on the continents. The crust is not a solid piece, like the shell of an egg, but is broken into pieces called plates. Magma comes close to the Earth's surface near the edges of these plates. This is where volcanoes occur. The lava that erupts from volcanoes is partly magma. Deep underground, the rocks and water absorb the heat from this magma. We can dig wells and pump the heated, underground water to the surface. People around the world use geothermal energy to heat their homes and to produce electricity, geothermal energy process that has been declared as shown in figure (1-3).
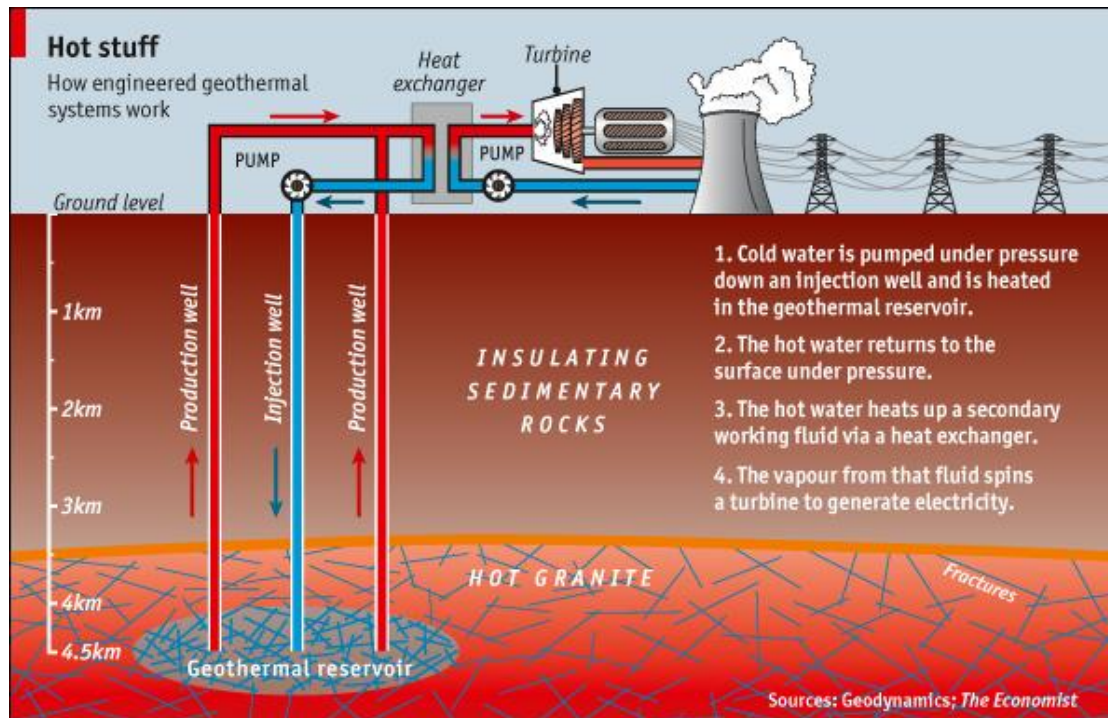
Figure (1-3) Geothermal energy process.
(Source: Geodynamics; The Economist).

Geothermal energy is called a renewable energy source because the water is replenished by rainfall and the heat is continuously produced deep within the Earth. We won't run out of geothermal energy [6]. Geothermal is the only form of 'renewable, energy that is independent of the sun, having its ultimate of heat source within the earth. It is a comparatively diffuse resource; the amount of heat flowing through the earth's surface, 10^{21} joules per annum (J a^{-1}) is tiny in comparison with the massive 5.4×10^{24} Ja^{-1} solar heating of the earth which also drives the atmosphere and hydrological cycles[7]. Using geothermal energy to produce electricity is a new industry. A group of Italians first used it in 1904. The Italians used the natural steam erupting from the Earth to power a turbine generator. The first successful American geothermal plant began operating in 1960 at The Geysers in northern California [6].

1.3   Photovoltaic Solar Energy

Photovoltaic solar energy conversion is the direct conversion of sunlight into electricity. This can be done by flat plate and concentrator systems as shown in figure (1-4). An essential component of these systems is the solar cell, in which the photovoltaic effect the generation of free electrons using the energy of light particles takes place. These electrons are used to generate electricity.
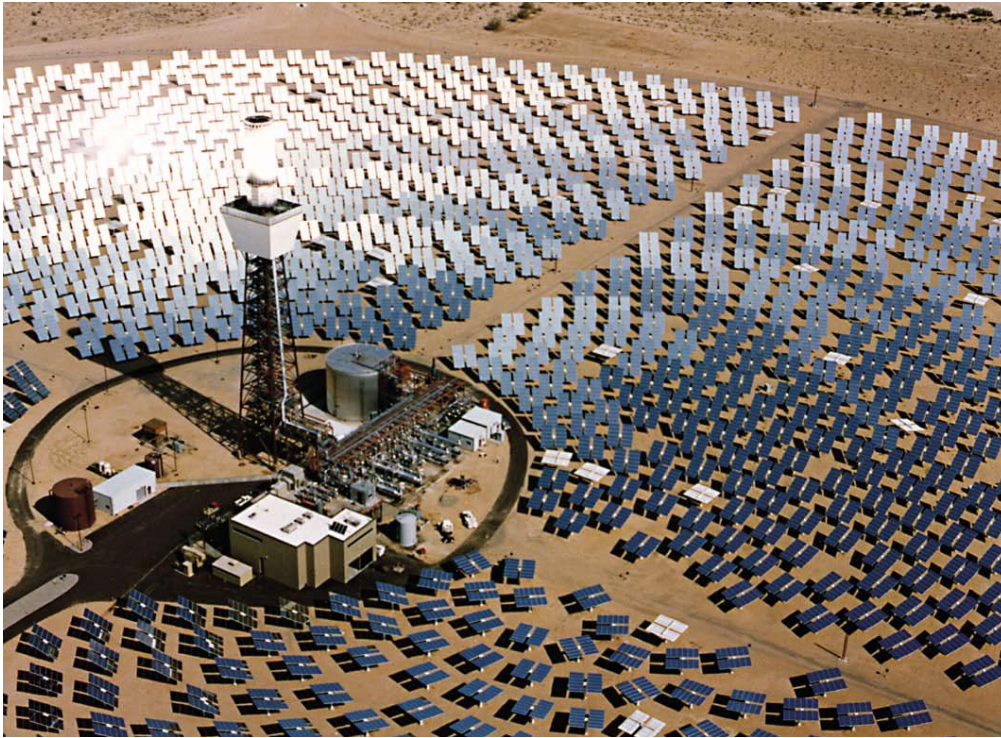
Figure (1-4): The solar power tower "Solar Two" in the Mojave desert in California.
(Photograph: Sandia National Laboratories, US Department of Energy/National Renewable Energy Laboratories).

Solar radiation is available at any location on the surface of the Earth. The maximum irradiance of sunlight on Earth is about 1,000 watts a square meter, irrespective of location. It is common to describe the solar source in terms of insolation the energy available per unit of area and per unit of time (such as kilo-watt-hours per square meter a year). The differences in average monthly insolation (June to December) can vary from 25 percent close to the equator to a factor of 10 in very northern and southern areas, determining the annual production pattern of solar energy systems. The ratio of diffuse to total annual insolation can range from 10 percent for bright sunny areas to 60 percent or more for areas with a moderate climate, such as Western Europe. The actual ratio largely determines the type of solar energy technology that can be used.
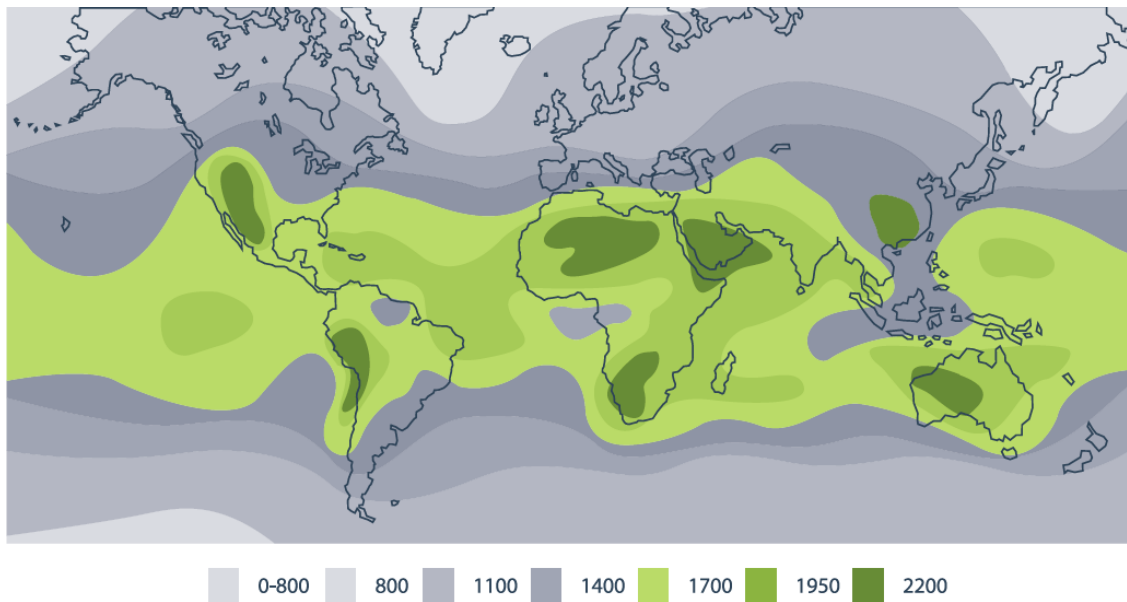
Figure (1-5): Yearly sum of direct beam insulations in the world kWh/m^2.
(Source: NASA. Illustration. Kim Brantenberg).

The average power density of solar radiation is 100-300 watts a square meter. The net conversion efficiency of solar electric power systems (sunlight to electricity) is typically 10-15 percent. So substantial areas are required to capture and convert significant amounts of solar energy to fulfill energy needs, especially in industrialized countries, relative to today's energy consumption[8].
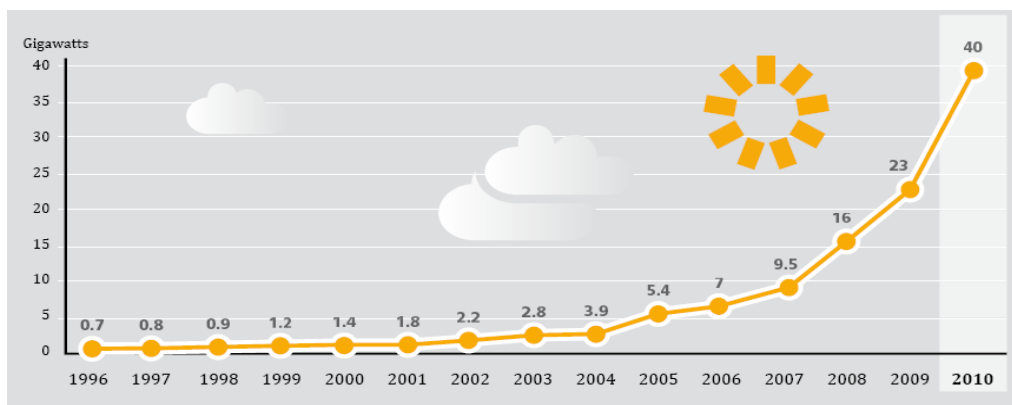
Figure (1-6) Solar PV Word Capacity, 1995-2010.
(Source: PV News, EPIA Renewable 2011 Global Status Report)

1.4   Wind Energy

1.4.1   Short Historical Review of wind energy

The force of the wind can be very strong, as can be seen after the passage of a hurricane or a typhoon. Historically, people have harnessed this force peacefully, its most important usage probably being the propulsion of ships using sails before the invention of the steam engine and the internal combustion engine. Wind has also been used in windmills to grind grain or to pump water for irrigation or, as in The Netherlands, to prevent the ocean from flooding low-lying land. At the beginning of the twentieth century electricity came into use and windmills gradually became wind turbines as the rotor was connected to an electric generator [9].

Development status: Globally, installed capacity increased from 2500 MW in 1992 to 59 200 MW at the end of 2005. This corresponds to an annual growth of about 30 percent. More than 75 percent of this new capacity has been installed in Europe.
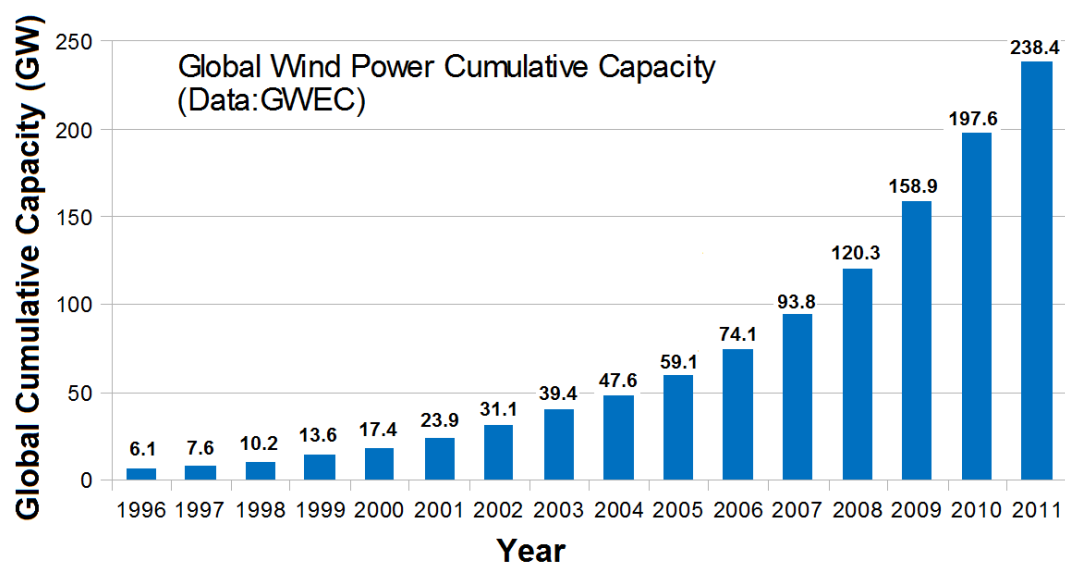
Figure (1-7) Global Wind Power Cumulative Capacity, 1996-2011.

In North America, all commercially available, utility-scale wind turbines from established turbine manufacturers utilize the 'Danish concept' turbine configuration. This configuration uses a horizontal axis, three-bladed rotor, an upwind orientation, and an active yaw system to keep the rotor oriented into the wind. The drive train consists of a low-speed shaft connecting the rotor to the gearbox, a 2- or 3-stage speed-increasing gearbox, and a high-speed shaft connecting the gearbox to the generator. Generators are typically asynchronous, induction, and operate at 550-690 V (AC). Some turbines are equipped with an additional small generator to improve production in low wind speeds. The second generator can be separate or integrated into the main generator. Each turbine for utility scale applications is equipped with a transformer to step up the voltage to the on-site collection system voltage. The on-site

collection system typically is operated at medium voltages of 25 to 35 kV. Figure (1-8) shows the major turbine components for a wind turbine[10].
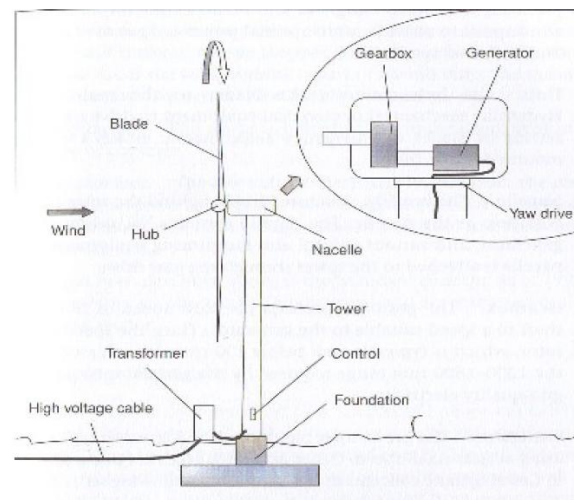
Figure (1-8) Major turbine components.
(Source: Wind Turbine Technology Overview, Global Energy Concepts,2005)

Of all renewable energy sources, wind power is the most mature in terms of commercial development. The development costs have decreased dramatically in recent years, however most projects are still dependent on public subsidies in order to be profitable. This energy source is interesting because of its renewability and its availability. Potential for development is huge, and the world's capacity is far larger than the world's total energy consumption.

Worldwide, a total capacity of about 60 000 MW have been installed, with a yearly production of about 100 TWh. The major challenges for further development are connected to economy, land usage, environment and grid capacity.

A wind turbine consists of tower, blades, and a nacelle containing the generator, gear and control system. The wind puts the blades in motion in the same way that an airplane wing gives lift to a plane. Energy is transferred from the turbine via the drive shaft to the generator inside the nacelle. The generator transforms the kinetic energy to electric energy, which is in turn transferred to the grid via a transformer.

A modern windmill produces energy when the wind speed is in the range of 4-25 m/s (gentle breeze to storm). Maximum output is achieved at 12-15 m/s, whilst the power production normally is stopped at wind speeds above 25 m/s (blade pitch is adjusted, brakes are applied) to protect the wind mill against damage.
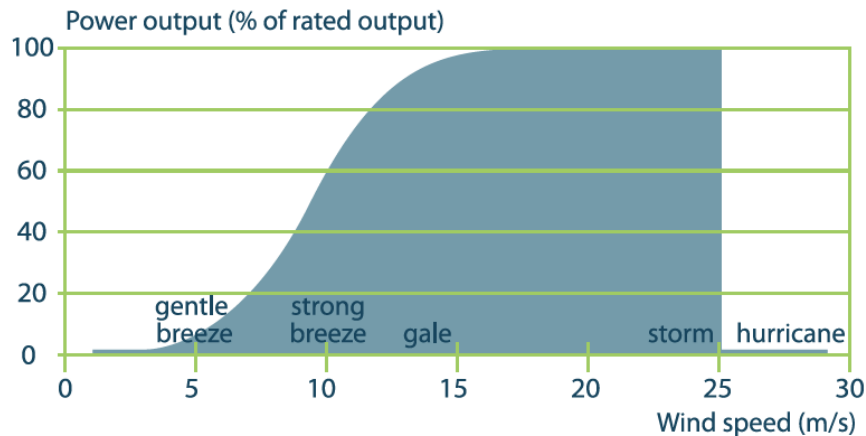
Figure (1-9) Normalized output curve for a wind turbine.
(Source: SINTEF Energy Research).

The energy output of wind increases exponentially in the third degree of the wind speed. Thus, even small changes in wind speed will have large effects on the energy production, and therefore the profitability of the project. A location with an average wind speed of 8 m/s will produce twice as much energy as a location with a average of 6 m/s. The wind properties of an area is therefore of prime importance [2].

1.4.2 General Types of wind generation equipment

Wind generation equipment is categorized into three general classifications.

1- Utility-Scale
Corresponds to large turbines (900 kW to 2 MW per turbine) intended to generate bulk energy for sale in power markets. They are typically installed in large arrays or 'wind energy projects,' but can also be installed in small quantities on distribution lines, otherwise known as distributed generation. Utility scale development is the most common form of wind energy development in the U.S.

2- Industrial-Scale
Corresponds to medium sized turbines (50 kW to 250 kW) intended for remote grid production, often in conjunction with diesel generation or load-side generation (on the customer's side of the meter) to reduce consumption of higher cost grid power and possibly to even reduce peak loads. Direct sale of energy to the local utility may or may not be allowed under state law or utility regulations.

3- Residential-Scale
Corresponds to micro- and small-scale turbines (400 watts to 50 kW) intended for remote power, battery charging, or net metering type generation. The small turbines can be used in conjunction with solar photovoltaics, batteries, and inverters to provide constant power at remote locations where installation of a distribution line is not possible or is more expensive [10].

1.4.3   Ratings and Rotor Size

The rotor diameters and rated capacities of wind turbines have continually increased in the past 10 years, driven by technology improvements, refined design tools, and the need to improve energy capture and reduce the cost of energy.
For comparison, the average turbine rating for turbines installed in the U.S. in 2001 was 908 kW, while turbines installed in 2003 had an average capacity of 1,374 kW. In 2005, turbines with rated capacities of 1.5 MW to 1.8 MW present the vast majority of the turbines sizes installed in North America. Figure (1-10) compares the height of a large wind turbine with other tall structures [10].
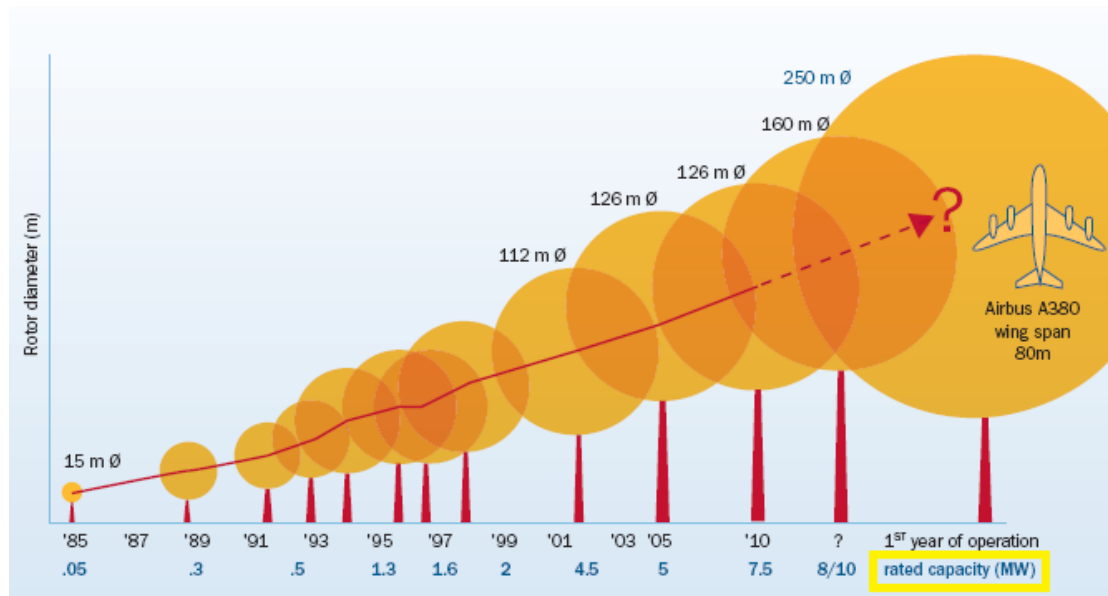
Figure (1-10): comparison the height of a large wind turbine with other tall structures.
(Source: http://www.nextbigfuture.com/2012/06/800-foot-tall-wind-turbines-are.html).

1.4.4   Environmental impacts

Operation of wind power has zero emissions of harmful substances. It does not add to global warming, the "fuel" is free, and is quite evenly distributed around the world. The energy needed to produce and install the turbine amounts to three months of turbine production. But, as with other sources of energy, wind power does have an environmental impact.

The impact of onshore and near-shore wind farms on wildlife - particularly migratory birds and bats - is hotly debated, and studies with contradictory conclusions have been published. The impact on wildlife is likely low compared to other forms of human and industrial activity. However, negative impacts on certain populations of sensitive species are possible, and efforts to mitigate these effects should be considered in the planning phase[2].

CHAPTER 2

LITERATURE REVIEW AND THESIS CONTRIBUTION

2.1 Literature Review

There have been several techniques and researches proposed so far to solve wind farm usage to generate electrical power. Here, a list of some previous researches interested in wind farm and applied cases will be shown as follow:

1- SHABBANEH and AFIF HASAN (1996) Wind energy potential in Palestine, Weibull parameters of the wind speed distribution function were computed for 49 weather stations in Palestine. Wind potentials in kWh/m 2 yr were calculated at the above stations, then contours of wind potential were drawn. Electricity from the wind can be generated, in some locations in the West Bank, at a cost of 0.07 S/kWh [11].

2- Prof.Dr. Hala J. El Khozondar and Amani Abu Reyala 2012, Load Reduction in Wind Energy Converters Using Individual Pitch Control, Developing the basic concept of individual pitch control of wind energy converter to get maximum possible value of power coefficient. For this purpose, reliable and efficient sensor, sensing bending moment, stresses and strains caused by wind, gravitational and centrifugal forces at the root of the blade, are very important. A simple model of the blade with analysis of the moments generated by the wind and the gravity of each blade, when the blade is rotating is provided and is checked by the real values measured by fiber Bragg grating sensors of Fos4x German Company [12].

3- Dr. Mohamed Ouda, Electrical and Computer Eng. Dept. IUG, Palestine. Prospects of Renewable Energy in the Gaza Strip studied the wind speed then he found that wind speed in the Gaza Strip is considered very low; therefore, potential wind applications are restricted partially to mechanical water pumping [13].

4- Dr. Imad Ibrik by Mohammad Husain Mohammad Dradi An-Najah National University, Nablus-Palestine Design and Techno Economical Analysis of a Grid Connected with PV/ Wind Hybrid System in Palestine (Atouf Village-

Case study) modeling the Grid tie PV/Wind hybrid system using Matlab Simulink software program in order to study the techno-economic performance analysis of building these systems according to our environmental conditions and collecting data such as temperature, solar radiation and wind speed [14].

5- Dr. Juma Yousuf Alaydi MODELING AND DYNAMIC ANALYSIS OF THE PERFORMANCE OF DIFFUSER AUGMENTED WIND TURBINE increasing the diffuser area as well as the negative back pressure at the diffuser exit was found profitable in the experiments. The aims to find a theoretical demonstration of DAWT by using theoretical analysis based on one-dimensional analysis, mathematical models, assumptions, estimations and maximization of power coefficients and augmentation ratios. With a simple momentum theory, developed along the lines of momentum theory for bare wind turbines, it was shown that power augmentation is proportional to the mass flow increase generated at the nozzle of the DAWT. Modeling and analysis of DAWT system were estimated and Improved for determining the power coefficient and augmentation ratio by Changing area ratio, diffuser efficiency, velocity ratio, turbine factor and Pressure recovery. Referred to rotor power coefficients values of C_p rotor =2.5 might be achievable according to theory, It was apparent that an optimal exit area ratio would depend upon economic arguments however; it appears unlikely that the exit-area-ratio would exceed a value around 315.

2.2 Thesis Contribution

- Developing a new strategy to deal with renewable energy presenting an analytical study of wind power in Palestine.

- Drawing a Weibull curve for the Gaza Strip and calculating the actual energy curve through Weibull curve.

- Calculating the amount of Energy that can be produced from each one meter square during the year.

- Calculating the cost of production per one kilowatt of energy.

- Calculating the payback period.

- Studying the Economic feasibility of wind power.

CHAPTER 3

WIND ENERGY PRODUCTION

This chapter illustrates the mechanical construction of wind turbine, and how each component affects the output energy. In addition to environment conditions that will help in increasing of useful energy. Finally the maximum limit can be reach by certain turbine.

3.1   Important Factors
3.1.1 Density of air

The kinetic energy of a moving body is proportional to its mass. The kinetic energy in the wind thus depends on the density of the air, i.e. its mass per unit of volume.

In other words, the "heavier" the air, the more energy is received by the turbine. At normal atmospheric pressure and at 15◦C, the density of air is 1.225 kg/m3, which increases to 1.293 kg/m3 at 0◦C and decreases to 1.164 kg/m3 at 30◦C. In addition to its dependence upon temperature, the density decreases slightly with increasing humidity. At high altitudes (in mountains), the air pressure is lower, and the air is less dense[21].

The wind power varies linearly with the air density sweeping the blades. The air density ρ varies with pressure and temperature in accordance with the gas law:

$$\rho = \frac{P}{RT} \tag{3.1}$$

Where,

P = air pressure

T = temperature on the absolute scale

R = gas constant

The air density at sea level ($\rho_\circ$), one atmospheric pressure (14.7 psi) and 60° F, equals 1.225 kg/m^3. Using this as a reference, ρ is corrected for the site specific temperature and pressure. The temperature and the pressure both in turn vary with the

altitude. Their combined effect on the air density is given by the following equation, which is valid up to 6000 meters of site elevation above the sea level:

$$\rho = \rho_0 \cdot e^{-\{\frac{0.297\ Hm}{3048}\}} \qquad (3.2)$$

Where H_m is the site elevation in meters, equation (3.2) can be simplified using Ln $ln(\rho) = ln(\rho_0 \cdot e^{-\{\frac{0.297\ Hm}{3048}\}})$ to equal equation (3.3)

$$\rho = \rho_o - 1.194 \times 10^{-4} \times H_m \qquad (3.3)$$

Replacing $\rho_\circ$ with its value at sea level gives us equation (3.4)

$$\rho = 1.225 - 1.194 \times 10^{-4} \times H_m \qquad (3.4)$$

Air density varies with temperature and elevation. Warm air is less dense than cold air. Any given wind turbine will produce less in the heat of summer than it will in the dead of winter with winds of the same speed.
The air density correction at high elevations can be significant. For example, the air density at 2,000-meter elevation would be 0.986 kg/m^3, 20 percent lower than the 1.225 kg/m^3 value at sea level[24]. For ready reference, the temperature varies with the elevation:

$$T = 15.5 - \frac{19.83\ H_m}{3048}\ °C \qquad (3.5)$$

3.1.2 Speed and Power Relations

The kinetic energy in air of mass "m" moving with speed V is given by equation (3.6)

$$\text{Kinetic Energy} = \frac{1}{2}.m.V^2 \text{joules} \qquad (3.6)$$

The power in moving air is the flow rate of kinetic energy per second.

Therefore,

$$\text{P} = \frac{1}{2}.\text{(mass flow rate per second)}.V^2 \qquad (3.7)$$

If we let,

P = mechanical power in the moving air

ρ = air density, kg/m^3

A = area swept by the rotor blades, m^2

V = velocity of the air, m/s

Then, the volumetric flow rate is A.V, the mass flow rate of the air in kilograms per second is ρ.A.V, and the power is given by equation (3.8):

$$P = \frac{1}{2}(\rho A V).V^2 = \frac{1}{2}\rho A V^3 \text{ Watts} \tag{3.8}$$

3.1.3 Power Output Increases with the Swept Rotor Area

The area of the disc covered by the rotor, determines how much energy can be harvested over a year. A typical 1,000 kW wind turbine has a rotor diameter of 54 m, i.e. a rotor area of some 2,300 m^2. The rotor area determines how much energy a wind turbine is able to harvest from the wind. Since the rotor area increases with the square of the rotor diameter, a turbine which is twice as large will receive 2^2, Four times as much as energy.
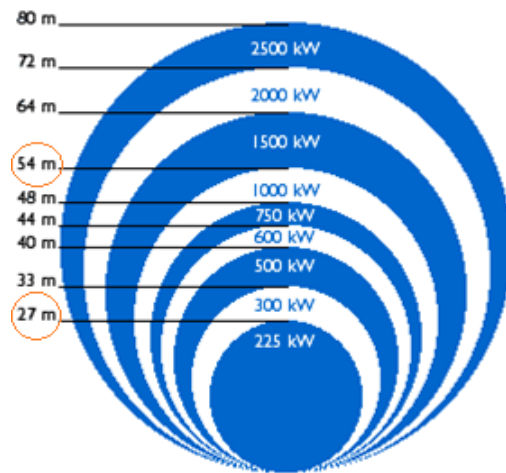
Figure (3-1): Relation between Power Output and Swept Rotor Area.
(Source: http://www.windpower.org , Guided Tour on Wind Energy).

The rotor swept area, A, is important because the rotor is the part of the turbine that captures the wind energy.

Double rotor diameter produces four-times increase in energy output as shown in figure (3-1), for example: at a rotor diameter of 27 m turbine produces 255 kW and with a rotor diameter of 54 m it produces 1,000 kW, in some cases in areas with low wind speed the rotor with a smaller diameter can produce more energy than rotors

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with a larger diameter, because if the configuration is smaller it will need less wind energy to rotate the smaller generator so the turbine can reach full capacity almost always.

3.1.4   Effect of Height

Wind velocity increases significantly with height, making horizontal axis wheels on towers more economical. the height of the tower is a key factor in the production of energy also the more the turbine is elevated the more energy it captures because the wind speed increases with height though ground friction and objects ground level interrupts wind flow. Scientists speculate that doubling height increases wind speed by 12% figure (3-2) shows the relation between height and wind speed.

Israel uses wind energy, derived from wind, in economical quantities, and where they constructed and plants containing high towers in areas of the Upper Galilee, Carmel, and Beni Amer, Negev Arran. They installed wind turbines with capacities of 1200 to 1300 kWh [23].
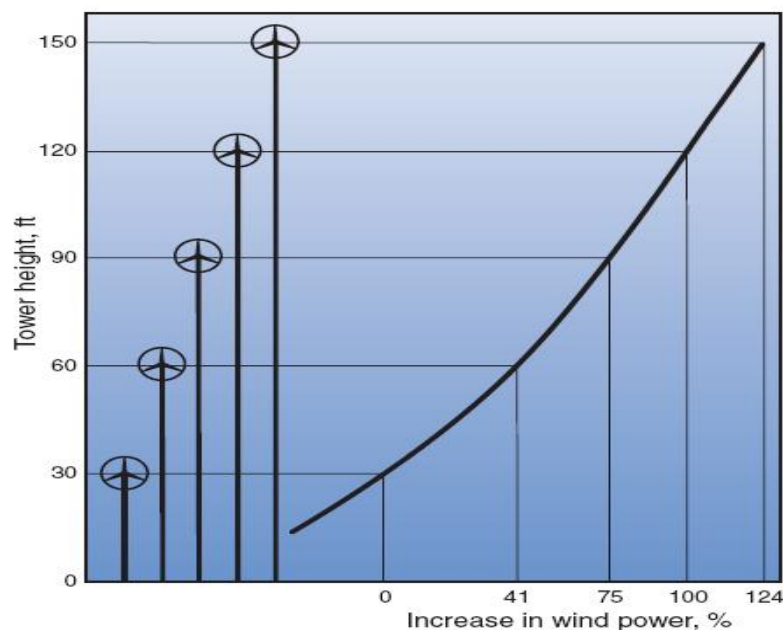
Figure (3-2): Relation between height and wind speed.

(Source: Small Wind Electric Systems A U.S. Department of Energy Wind Energy Program).

Wind speeds are affected by the friction against the surface of the earth. The wind shear at ground surface causes the wind speed increase with height in accordance with the expression:

$$V_2 = V_1 \left(\frac{h_2}{h_1}\right)^\alpha \qquad\qquad (3.9)$$

Where V_1 = wind speed measured at the reference height h_1

$\qquad V_2$ = wind speed estimated at height h_2

$\qquad \alpha$ = ground surface friction coefficient

The friction coefficient is low for smooth terrain and high for rough ones [22]. The values of α for typical terrain classes are given on the following table:

Table 3.1 Friction Coefficient of Various Terrains[22].

Terrain Type	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 trees	0.25
Small towns with some trees and shrubs	0.30
City area with tall buildings	0.40

High above ground level the wind is influenced by the surface of the earth at all. In the lower layers of the atmosphere, however, wind speeds are affected by the friction against the surface of the earth. In the wind industry one distinguishes between the roughness of the terrain, the influence from obstacles, and the influence from the terrain contours, which is also called the orography of the area.

The more pronounced the roughness of the earth's surface, the more the wind will be slowed down. In the wind industry, wind conditions in a landscape are referred through roughness classes or roughness lengths. The term roughness length is the distance above ground level where the wind speed theoretically should be zero. A high roughness class of 3–4 refers to landscapes with many trees and buildings while a sea surface is in roughness class 0. Concrete runways in airports are in roughness class 0.5 [21].

3.2   Betz' Law

Betz' law says that you can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine. Betz' law was first formulated by the German Physicist Albert Betz in 1919. His book "Wind-Energies" published in 1926 gives a good account of the knowledge of wind energy and wind turbines at that moment.

The more kinetic energy a wind turbine pulls out of the wind, the more the wind will be slowed down as it leaves the left side of the turbine in figure (3-3) as V_1 is the input power and V_2 is the output power. If we tried to extract all the energy from the wind, the air would move away with the speed zero, i.e. the air could not leave the turbine.

In that case we would not extract any energy at all, since all of the air would obviously also be prevented from entering the rotor of the turbine. In the other extreme case, the wind could pass though our tube above without being hindered at all. In this case we would likewise not have extracted any energy from the wind.
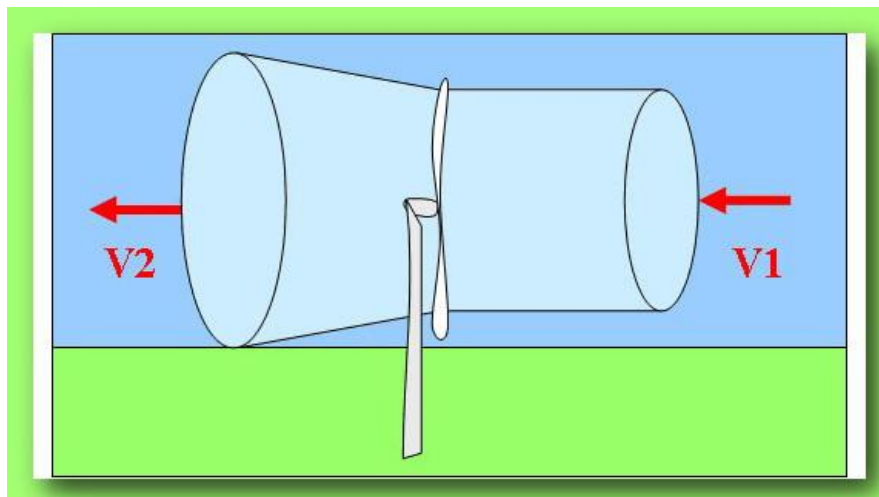
Figure (3-3) Stream tube around turbine.

We can therefore assume that there must be some way of braking the wind which is in between these two extremes, and is more efficient in converting the energy in the wind to useful mechanical energy. It turns out that there is a surprisingly simple answer to this: An ideal wind turbine would slow down the wind by 2/3 of its original speed.
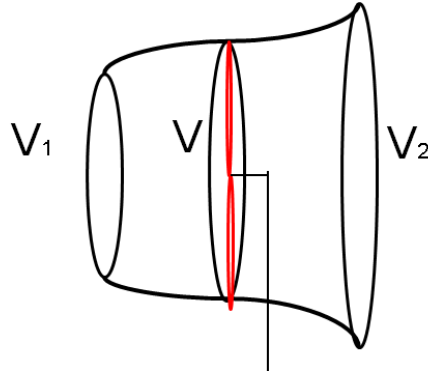
Figure (3-4) Relation between V_1 and V_2.

Figure (3-4) is a bit simplified. In reality, a wind turbine will deflect the wind, even before the wind reaches the rotor plane. This means that we will never be able to capture all of the energy in the wind using a wind turbine. The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers as shown in equation (3.10):

$$P_\circ = \frac{1}{2} \; mass \; flow \; rate \; per \; second. \{V^2 - \; V_\circ^2\} \qquad (3.10)$$

Where

$P_\circ$ = mechanical power extracted by the rotor, i.e., the turbine output power.
V = upstream wind velocity at the entrance of the rotor blades.
$V_\circ$ = downstream wind velocity at the exit of the rotor blades.

The air velocity is discontinuous from V to Vo 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. As shown in equation (3.11):

$$mass \; flow \; rate = \; \rho \,.\, A \,.\, \frac{V + V_\circ}{2} \qquad (3.11)$$

The mechanical power extracted by the rotor, which is driving the electrical generator, is therefore:

$$P_\circ = \frac{1}{2} \left[\rho \,.\, A \,.\, \frac{V + V_\circ}{2} \right] .(V^2 - V_\circ^2) \qquad (3.12)$$

Equation (3.12) can be algebraically rearranged as shown in equation (3.13):

19

$$P_\circ = \frac{1}{2}\ \rho\,.\,A\,.\,V^3\ \frac{\left(1+\frac{V_\circ}{V}\right)\left[1-\left(\frac{V_\circ}{V}\right)^2\right]}{2} \qquad\qquad (3.13)$$

The power extracted by the blades is customarily expressed as a fraction of the upstream wind power as equation (3.14) shows

$$P_\circ = \frac{1}{2}\ \rho\,.\,A\,.\,V^3.\,C_p \qquad\qquad (3.14)$$

Where

$$C_p = \frac{\left(1+\frac{V_\circ}{V}\right)\left[1-\left(\frac{V_\circ}{V}\right)^2\right]}{2} \qquad\qquad (3.15)$$

The C_p is the fraction of the upstream wind power, which is captured by the rotor blades. The remaining power is discharged or wasted in the downstream wind. The factor C_p is called the power coefficient of the rotor or the rotor efficiency.
For a given upstream wind speed, the value of C_p depends on the ratio of the downstream to the upstream wind speeds, that is ($V_\circ/V$). The plot of power coefficient versus ($V_\circ/$ V) shows that C_p is a single, maximum-value function. It has the maximum value of 0.59 when the ($V_\circ/$ V) is one-third. The maximum power is extracted from the wind at that speed ratio, when the downstream wind speed equals one-third of the upstream speed. As sown in equation(3.16)

$$P_{max} = \frac{1}{2}\ \rho\,.\,A\,.\,V^3\,.0.59 \qquad\qquad (3.16)$$

The theoretical maximum value of C_p is 0.59. In practical designs, the maximum achievable C_p is below 0.5 for high-speed, two-blade turbines, and between 0.2 and 0.4 for slow speed turbines with more blades. If we take 0.5 as the practical maximum rotor efficiency, the maximum power
output of the wind turbine becomes a simple expression as shown in Figure (3-5).
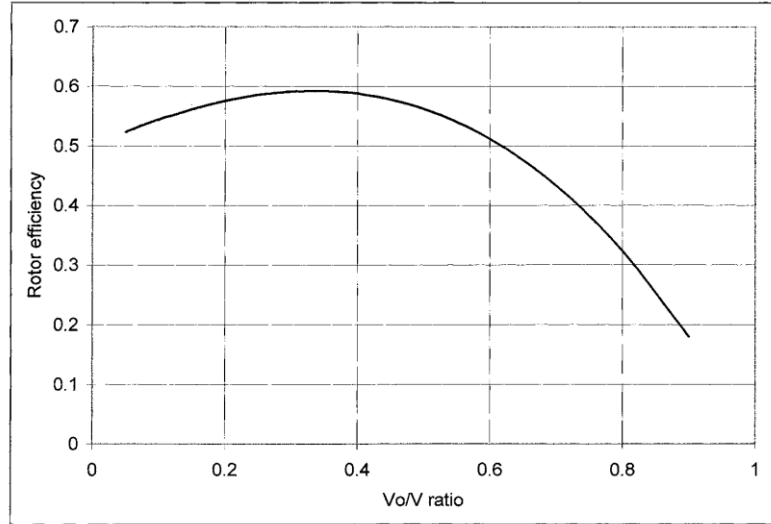
Figure (3-5): Rotor efficiency versus (V_o/ V) ratio has single maximum.
(Source: Wind and Solar Power Systems Mukund R. Patel, Ph.D., P.E. U.S. Merchant Marine
Academy Kings Point, New York[22]).

Rotor efficiency is the fraction of available wind power extracted by the rotor and fed to the electrical generator as shown in equation(3.17):

$$P_{max} = \frac{1}{4} . \rho . V^3 \; watts \; per \; m^2 \; of \; swept \; area. \qquad (3.17)$$

3.3 Power of wind

$$P_{air} = \frac{1}{2} \rho A v^3 \qquad (3.18)$$

Where

ρ = air density (approximately 1.225 kg/m^3)
A = swept area of rotor, m^2
v = upwind free wind speed, ms^{-1}.

Although Equation (3.18) gives the power available in the wind the power transferred to the wind turbine rotor is reduced by the power coefficient, C_p:

$$C_p = \frac{P_{wind \; turbine}}{P_{air}} \qquad (3.19)$$

Where

$$P_{wind\ turbine} = C_p P_{air} = C_p \times \frac{1}{2}\ \rho\ Av^3 \qquad (3.20)$$

A maximum value of Cp is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum C_p values in the range 25–45%. It is also conventional to define a tip-speed ratio, λ, as:

$$\lambda = \frac{\omega R}{v} \qquad (3.21)$$

Where
  ω = rotational speed of rotor
  R = radius to tip of rotor
  v = upwind free wind speed, ms^{-1}.

The tip-speed ratio, λ, and the power coefficient, C_p, are dimensionless and so can be used to describe the performance of any size of wind turbine rotor. The maximum power coefficient is only achieved at a single tip-speed ratio and for a fixed rotational speed of the wind turbine this only occurs at a single wind speed. Hence, one argument for operating a wind turbine at variable rotational speed is that it is possible to operate at maximum C_p over a range of wind speeds.

3.4   Tip-speed ratio

The tip-speed ratio λ (lambda) or TSR for wind turbines is the ratio between the rotational speed of the tip of a blade and the actual velocity of the wind. If the velocity of the tip is exactly the same as the wind speed, the tip-speed ratio is 1.0. The tip-speed ratio is related to efficiency, with the optimum varying with blade design. The speed of the tip of one blade depends on the revolutions per minute (or rpm), and the rotor diameter [27].

$$Tip\ speed\ ratio = \frac{Tip\ speed\ of\ blade}{wind\ speed} \qquad (3.22)$$

The relation between the wind speed and the rate of the rotor is characteristic by anon dimensional factor known as the TSR or lambda:

$$\text{Tip speed ratio}: \lambda = \frac{speed\ of\ rotor\ tip}{wind\ speed} = \frac{v}{V} = \frac{\omega R}{V} \qquad (3.23)$$

Where

V	is the wind speed [m/sec]
$v = \omega R$	is velocity of rotor tip [m/sec]
r	is rotor radius [m]
$\omega = 2\pi f$	is the angular velocity [radian/sec]
f	is the frequency of rotation [Hz], [sec^{-1}]

The tip-speed ratio, λ, and the power coefficient, C_p, are dimensionless and so can be used to describe the performance of any size of wind turbine rotor[28],[29].

3.5 Wind Turbine Power Curves

3.5.1 Power curve

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds [24].The power curve of a wind turbine follows this relationship between cut-in wind speed (the speed at which the wind turbine starts to operate) and the rated capacity, approximately as shown in Figure (3-6). The wind turbine usually reaches rated capacity at a wind speed of between 12 to 16 ms^{-1}, depending on the design of the individual wind turbine [25].
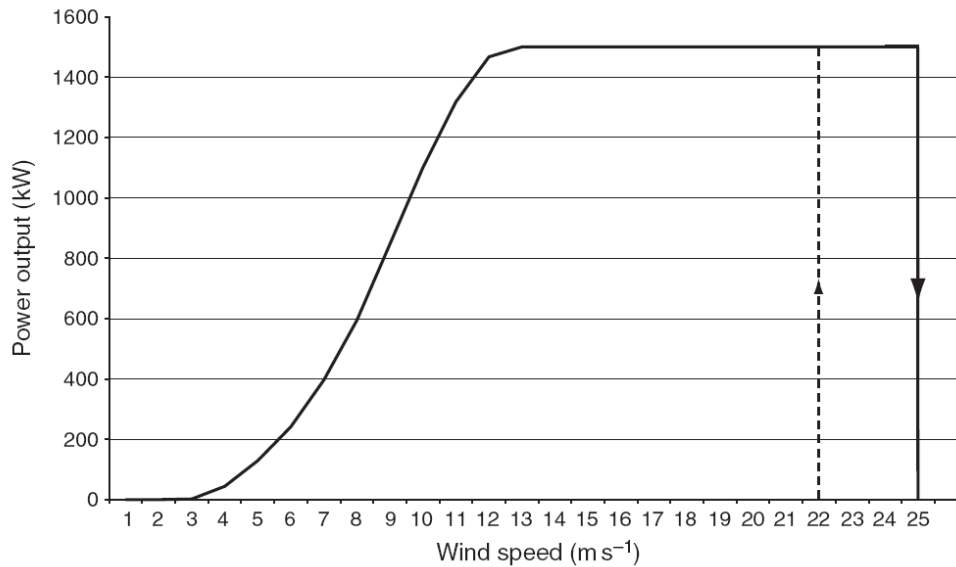
Figure (3-6) Relationship between wind velocity and power of wind.
(Source: Wind Power in Power Systems , Thomas Ackermann).

1- Max power output

Or rated power of the turbine, the constant power output maintained above the rated wind speed.

2- The Cut in Wind Speed

Wind speed at which the wind turbine is designed to start running.

3- The Cut out Wind Speed

The wind turbine will be programmed to stop at high wind speeds above, say 25 meters per second, in order to avoid damaging the turbine or its surroundings. The stop wind speed is called the cut out wind speed.

3.5.2 Uncertainty in Measurement of Power Curves

In reality, one will see a swarm of points spread around the line, and not the neat curve in the graph. The reason is that in practice the wind speed always fluctuates, and one cannot measure exactly the column of wind that passes through the rotor of the turbine. (It is not a workable solution just to place an anemometer in front of the turbine, since the turbine will also cast a "wind shadow" and brake the wind in front of itself).

In practice, therefore, one has to take an average of the different measurements for each wind speed, and plot the graph through these averages. Furthermore, it is

difficult to make exact measurements of the wind speed itself. If one has a 3 per cent error in wind speed measurement, then the <u>energy</u> in the wind may be 9 per cent higher or lower. Consequently, there may be errors up to plus or minus 10 per cent even in certified power curves[24].

3.5.3 Relationship of Wind Speed to Power Production

The relationship between wind speed and power is defined by a power curve, which is unique to each turbine model and, in some cases, unique to site-specific settings. In general, most wind turbines begin to produce power at wind speeds of about 4 m/s (9 mph), achieve rated power at approximately 13 m/s (29 mph), and stop power production at 25 m/s (56mph). Variability in the wind resource results in the turbine operating at continually changing power levels. At good wind energy sites, this variability results in the turbine operating at approximately 35% of its total possible capacity when averaged over a year[10].As shown in Figure (3-7), power production from a wind turbine is a function of wind speed.
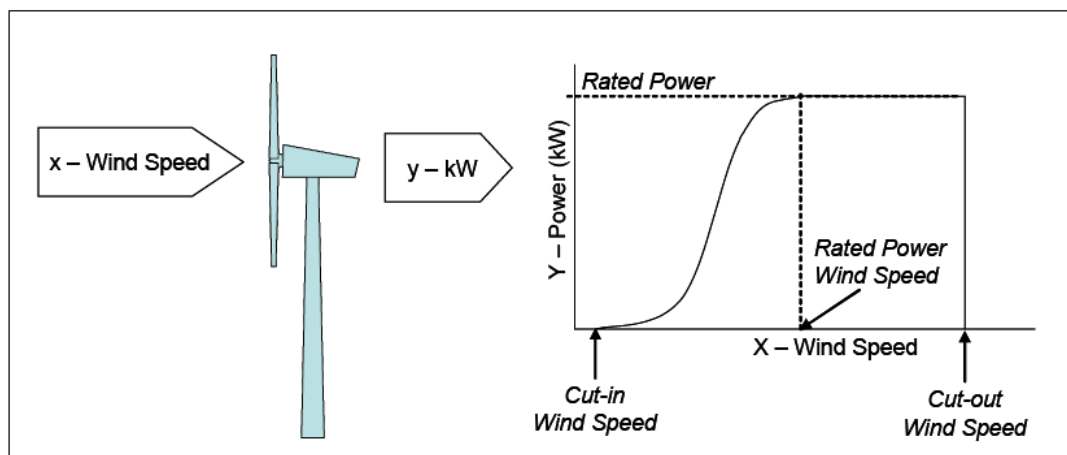
Figure (3-7) Relationship of wind speed to power production.
(Source: Wind Turbine Technology Overview, Global Energy Concepts, 2005)

3.5.4 Weibull Probability Distribution

The Weibull probability function, equation, is the most widely used distribution in wind energy studies, Weibull distribution describing the wind variation for a typical site. The area under the curve is always exactly 1, since the probability that the wind will be blowing at some wind speeds including zero must be 100 percent. The distribution of wind speeds is skewed; it is not symmetrical. The Weibull probability density distribution function is given by equation(3.24).

$$F(v) = K * \frac{V^{(K-1)}}{C^K} * e^{-(\frac{V}{C})^K} \qquad\qquad (3.24)$$

Where

K: is the Weibull shape factor; it gives an indication about the variation of
Hourly average wind speed about the annual average,
C: is the Weibull scale factor[40].
V: is the wind speed.

It is very important for the wind industry to be able to describe the variation of
wind speeds. Turbine designers need the information to optimize the design of their
turbines, so as to minimize generating costs. Turbine investors need the information to
estimate their income from electricity generation[24].
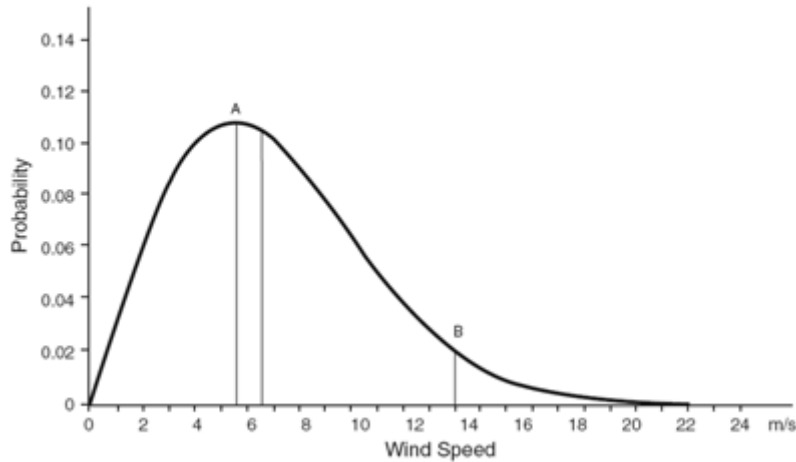
Figure (3-8) Weibull distribution plot between wind velocity and probability.
(Source: Introduction to Wind Energy Systems Basics, Technology and Operation, Hermann-Josef
Wagner J. yotirmay Mathur)

The wind variation for a typical site is usually described using the so called
Weibull distribution, as shown in the figure (3-8). This particular site has a average
wind speed of 7 meters per second, and the shape of the curve is determined by a so
called shape parameter of 2[24].
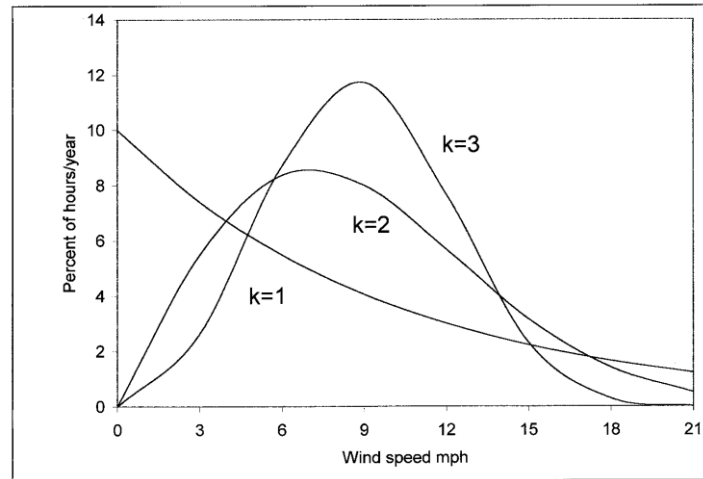
Figure (3-9) Effect shape factor on the Weibull Curve.
(Source: Wind and Solar Power Systems, Mukund R. Patel, Ph.D., P.E. U.S. Merchant Marine
Academy Kings Point, New York[22]).

In figure (3-9) the curve in the middle with k = 2 is a typical wind distribution found at most sites. In this distribution, more days have lower than the average speed, while few days have high wind. The value of k determines the shape of the curve, hence is called the 'shape parameter'. The Weibull distribution with k = 1 is called the exponential distribution which is generally used in the reliability studies. For k>3, it approaches the normal distribution, often called the Gaussian or the bell-shape distribution [24].

3.5.5 Power Density Function

We know that the energy potential per second (the <u>power</u>) varies in proportion to the cube (the third power) of the wind speed, and in proportion to the density of the air. (Its weight per unit of volume).We may now combine everything we have learned so far: If we multiply the <u>power</u> of each wind speed with the probability of each wind speed from the <u>Weibull</u> graph, we have calculated the distribution of wind energy at different wind speeds which is the power density.
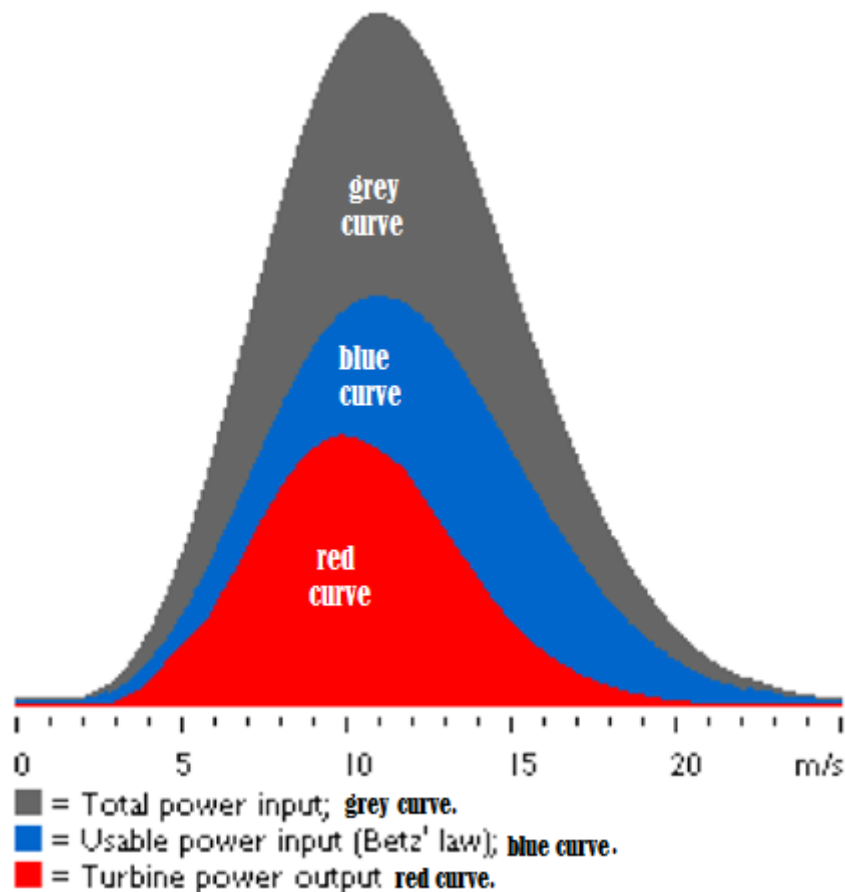
Figure (3-10) Power Density Curve.
(Source: http://www.windpower.org , Guided Tour on Wind Energy).

In figure (3-10) ,The area under the grey curve (all the way to the axis at the bottom) gives us the amount of wind power per square meter wind flow we may expect at this particular site. In this case we have a average wind speed of 7 m/s and a Weibull k=2, so we get 402 W/m^2. You should note that this is almost twice as much power as the wind has when it is blowing constantly at the average wind speed.

The graph consists of a number of narrow vertical columns, one for each 0.1 m/s wind speed interval. The height of each column is the power (number of watts per square meter), which that particular wind speed contributes to the total amount of power available per square meter.

The area under the blue curve tells us how much of the wind power we can theoretically convert to mechanical power. (According to Betz' law, this is 16/27 of the total power in the wind). The total area under the red curve tells us how much electrical power a certain wind turbine will produce at this site[24].

Verifying Power Curves: Power curves are based on measurements in areas with low turbulence intensity, and with the wind coming directly towards the front of the turbine. Local turbulence and complex terrain (e.g. turbines placed on a rugged slope) may mean that wind gusts hit the rotor from varying directions. It may therefore be difficult to reproduce the power curve exactly in any given location[24].

3.5.6 The Power Coefficient C_p

The power coefficient tells you how efficiently a turbine converts the energy in the wind to electricity. C_p = Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59).

Very simply, we just divide the electrical power output by the wind energy input to measure how technically efficient a wind turbine is. In other words, {we take the power curve, and divide it by the area of the rotor to get the power output per square meter of rotor area. For each wind speed, we then divide the result by the amount of power in the wind per square meter.

Figure (3-11) shows a power coefficient curve for a typical Danish wind turbine. Although the average efficiency for these turbines is somewhat above 20 per cent, the efficiency varies very much with the wind speed. (If there are small kinks in the curve, they are usually due to measurement errors)[24].
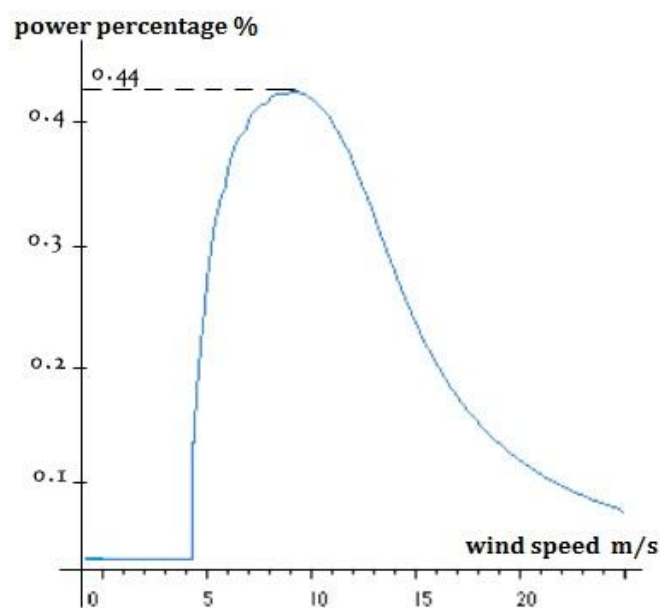
Figure (3-11) Power coefficient curve for a typical Danish wind turbine.
(Source: http://www.windpower.org , Guided Tour on Wind Energy).

As you can see in figure (3-11), the mechanical efficiency of the turbine is largest (in this case 44 per cent) at a wind speed around some 9 m/s. This is a deliberate choice by the engineers who designed the turbine. At low wind speeds efficiency is not so important, because there is not much energy to harvest. At high wind speeds

the turbine must waste any excess energy above what the generator was designed for. Efficiency therefore matters most in the region of wind speeds where most of the energy is to be found [24].

3.6   Wind Turbines

1- Horizontal Axis Wind Turbines HAWTs

Turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). The purpose of the rotor, of course, is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades as shown in figure (3-12).
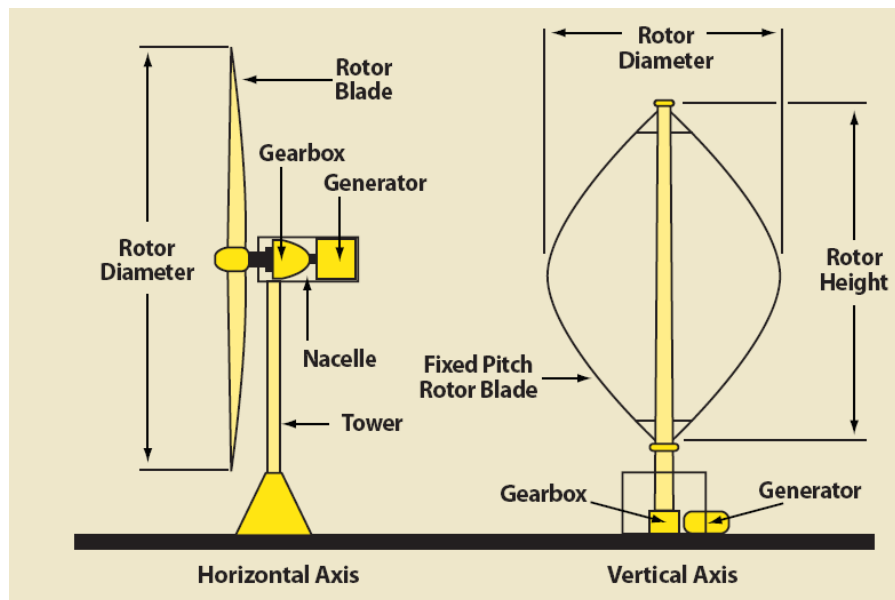
Figure (3-12) Horizontal Axis Wind and Vertical Axis Wind Turbines.

(Source: The Energy Report May 2008, American Wind Energy Association).

2- Vertical Axis Wind Turbines VAWTs

The only vertical axis turbine which has ever been manufactured commercially at any volume is the Darrieus machine, named after the French engineer Georges Darrieus who patented the design in 1931.

The basic theoretical advantages of a vertical axis machine are
1- You may place the generator, gearbox etc. on the ground, and you may not need a tower for the machine.
2- You do not need a yaw mechanism to turn the rotor against the wind.

Figure (3-13) A 4.2 MW vertical axis Darrieus wind turbine.
(Source: www.reuk.co.uk).

The basic disadvantages are:

1- Wind speeds are very low close to ground level, so although you may save a tower, your wind speeds will be very low on the lower part of your rotor.
2- The overall efficiency of the vertical axis machines is not impressive.
3- The machine is not self-starting (e.g. a Darrieus machine will need a "push" before it starts. This is only a minor inconvenience for a grid connected turbine, however, since you may use the generator as a motor drawing current from the grid to start the machine).

Studying wind turbine types and recognizing law wind speed in Palestine, makes HAWT the most suitable type to be used in Palestine, as this type produces much more energy than VAWT. Therefore, concentration will be on HAWT, knowing that this type of turbines is used the most in the world.

3.7 Mechanical construction

Figure (3-14) shows the construction of wind turbine including swept area (rotor diameter), main parts of wind turbine and inner components.
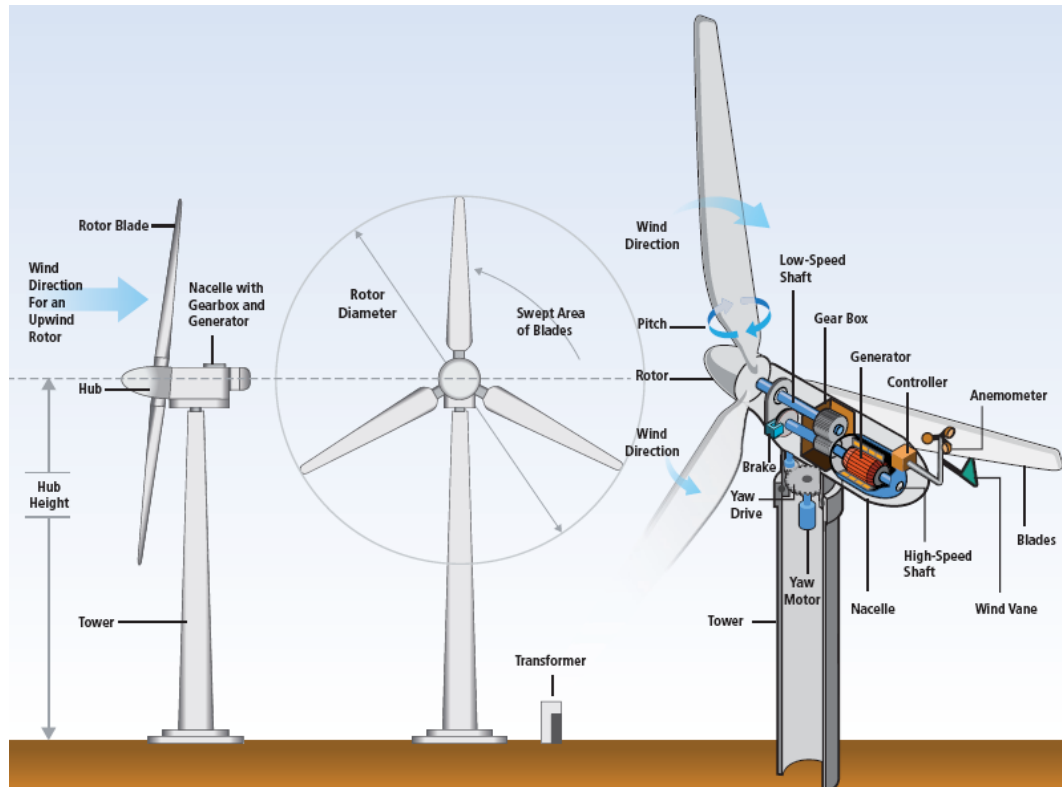
Figure (3-14) wind turbine construction.
(Source: National Renewable Energy Laboratory "NREL").

1-   Blade

Turbine blades have aerodynamic wings that create lift and rotation of the rotor as the wind blows across them. The blades are connected to a central cone called the hub, which is connected to a shaft that passes into the nacelle.

2-   Anemometer

An instrument used to measure the velocity, or speed, of the wind. Cup anemometers are the standard type used today, with cups spinning on a vertical axis. The anemometer typically is installed on a met tower at the anticipated location and height of the potential wind turbine, Anemometer is shown in figure (3-15).

Figure (3-15) Anemometer.

3-   Nacelle

The structure at the top of the wind turbine tower just behind (or, in some cases, in front of) the wind turbine blades that houses the key components of the wind turbine, including the rotor shaft, gearbox, and generator [16].

The nacelle is the enclosure at the top of the tower that contains the drive shaft, gearbox, generator, electronic controls and associated equipment. The nacelle is reached by a ladder that runs inside the tower so technicians can access the turbine components for maintenance and repair [17].

4-   Wind direction

This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

5-   Rotor

Comprises the spinning parts of a wind turbine, including the turbine blades and the hub.

6-   Pitch

Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

7-   Brake

A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

8-   High-speed shaft

Drives the generator.

9-   Low-speed shaft

The rotor turns the low-speed shaft at about 30 to 60 rpm. Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rpm to about 1000 to 1800 rpm the rotational speed required by most generators.

10-   Generator

The wind turbine generator converts mechanical energy to electrical energy. Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

11-   Wind vane

Measures wind direction and communicate with the yaw drive to orient the turbine properly with respect to the wind, wind vane as shown in figure (3-16).

Figure (3-16) Wind Vane.

12-   Yaw system

The yaw deck allows the rotor and nacelle to align with the wind the yaw deck is able to turn three complete revolutions before locking to ensure the cables are not twisted. It will then reset itself yaw system as shown in Figure (3-17).
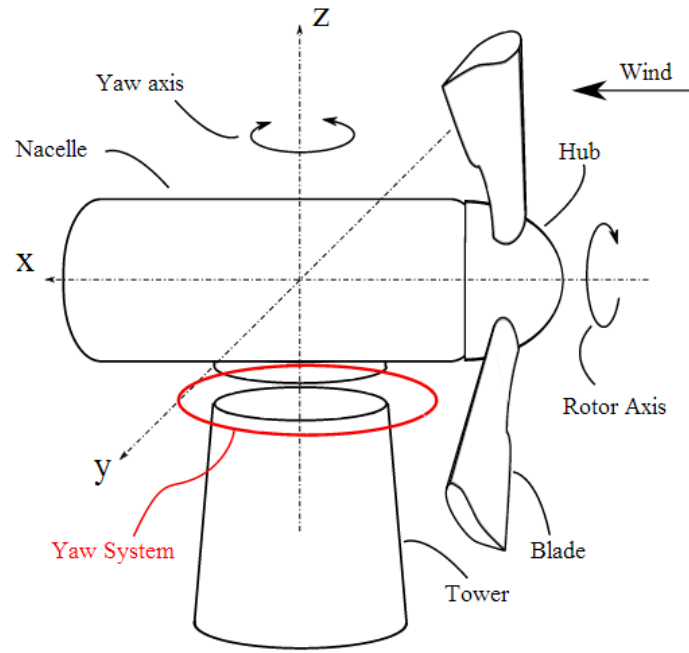
Figure (3-17) Yaw system.

13-   Yaw drive

Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.

14-   Yaw motor

Powers the yaw drive.

15-   Wind direction

This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind [18].

16-   Tower

The tower of the wind turbine carries the nacelle and the rotor blades. The tower needs to be as tall as possible, because the wind speed increases with height. Modern turbines are typically constructed using a tubular steel tower. Older wind turbines and windmills used the lattice type tower, which consists of a crisscrossed network of steel or wood members.

3.8   Types of Tower

1- Tubular Steel Towers

Most large wind turbines are delivered with tubular steel towers, which are manufactured in sections of 20-30 meters with flanges at either end, and bolted together on the site. The towers are conical (i.e. with their diameter increasing towards the base) in order to increase their strength and to save materials at the same time steel tower as shown in Figure (3-18).

Figure (3-18) Steel tower.
(Source: IEA Wind 2010 Annual Report).

2- Lattice Towers

Lattice towers are manufactured using welded steel profiles. The basic advantage of lattice towers is cost, since a lattice tower requires only half as much material as a freely standing tubular tower with a similar stiffness. The basic disadvantage of lattice towers is their visual appearance. Be that as it may, for aesthetic reasons lattice towers have almost disappeared from use for large, modern wind turbines [19], lattice towers as shown in figure (3-19).

Figure (3-19) lattice towers.
(Source: Wind Power Today U.S. Department of Energy).

3- Guyed Pole Towers

Some towers are made in different combinations of the techniques mentioned above. One example is the three-legged Bonus 95 kW tower which you see in the photograph, which may be said to be a hybrid between a lattice tower and a guyed tower. Guyed pole towers are only used for small wind turbines, this type of tower is shown in figure (3-20).
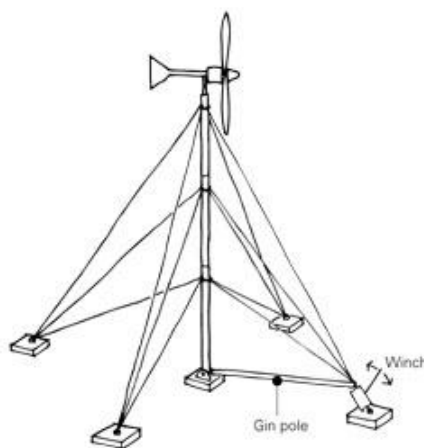
Figure (3-20) Guyed Pole Towers.

3.9   Number of Blades

This is the first determination the design engineer must make. Many people intuitively feel that more blades will produce more power, Fast Rotation converters consist of only a few aerodynamically optimized rotor blades, and slow rotation converters as the multi-bladed wind energy as shown in figure (3-21). The high number of blades was used in old low, tip-speed ratio rotors for water pumps, and the application which needs high starting torque. The modern high, tip-speeds ratio rotors for generating electrical power have two or three blades, many of them with just two.

Figure (3-21) Multi-Blade Wind Turbine.

Modern wind turbine engineers avoid building large machines with an even number of rotor blades. The most important reason is the stability of the turbine. A rotor with an odd number of rotor blades (and at least three blades) as shown in figure(3-22) can be considered to be similar to a disc when calculating the dynamic properties of the machine.
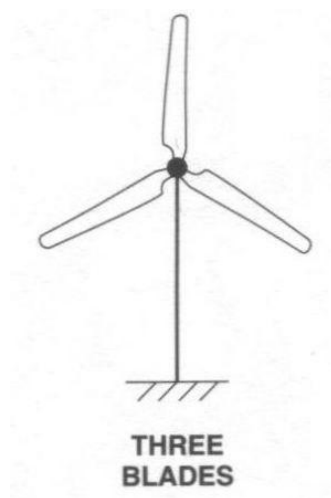
THREE BLADES

Figure (3-22) Three-Bladed Wind Turbine.

3.10 Foundation

Foundation plays a very important role in stabilizing the wind turbine. In general, the foundation design is based on the weight and configuration of the proposed turbine, the expected maximum wind speeds, and the soil characteristics at the site. Due to the large height, heavy weight at the nacelle and large rotor area which faces wind forces, the role of a foundation becomes very important [20]. While in case of on-shore installations, the type of foundation depends upon the nature of the soil, in case of off-shore turbines, it becomes an even more serious issue[10], the Different types of foundations used in offshore turbines shown in figure (3-23).
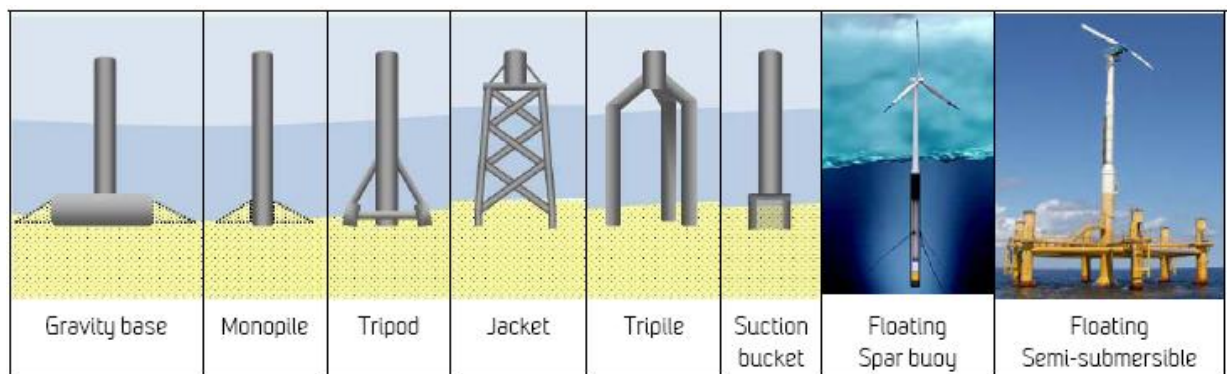
Figure (3-23) Different types of foundations used in offshore turbines.
(Source: http://www.offshorewind.de , and EWEA, 2009).

3.11   Advantages and Disadvantages of Wind Energy Systems

1- Advantages

1. A wind turbine which is made for capturing wind energy needs little land to be built. The rest of the land can be effectively used for agricultural purposes.
2. Wind energy is friendly to the surrounding environment, as no fossil fuels are burnt to generate electricity from wind energy.
3. Wind energy is available as a domestic source of energy in many countries worldwide and not confined to only few countries, as in case of oil.
4. Wind energy is one of the lowest-priced renewable energy technologies available today.
5. Wind turbines can also be built on farms or ranches, thus benefiting the economy in rural areas, where most of the best wind sites are found. Farmers and ranchers can continue to use their land because the wind turbines use only a small fraction of the land. Wind power plant owners make rent payments to the farmer or rancher for the use of the land.
6. Another advantage of wind energy is that when combined with solar electricity, this energy source is great for developed and developing countries to provide a steady, reliable supply of electricity.

2- Disadvantages

1.   The major challenge to using wind as a source of power is that the wind is intermittent and it does not always blow when electricity is needed.
2. Good wind sites are often located in remote locations, far from cities where the electricity is needed. In developing countries, there is always the extra cost of laying grid for connecting remote wind farms to the supply network.
3. Wind turbine construction can be very expensive and costly to surrounding wildlife during the build process.
4. The noise pollution from commercial wind turbines is sometimes similar to a small jet engine. This is fine if you live miles away, where you will hardly notice the noise, but what if you live within a few hundred meters of a turbine This is a major disadvantage[20].

Today, various types of wind energy converters are in operation. The most common device is the horizontal axis converter. This converter consists of only a few aerodynamically optimized rotor blades, which for the purpose of regulation can

usually be turned about their long axis pitch controller (Pitch-regulation). Another cheaper way of regulation consists in designing the blades in such a way that the air streaming along the blades will go into turbulence at a certain speed (Stall-Regulation). Another conventional (older) type of horizontal axis rotor is the multi-blade wind energy converter. It have a high starting torque which makes them suitable for driving mechanical water pumps. The number of rotations is low, and the blades are made from simple sheets with an easy geometry.

For pumping water, a rotation regulating system is not necessary, but there is a mechanical safety system installed to protect the converter against storm damage.

In order to increase the number of rotations, this type of converter had been improved and equipped with aerodynamically more efficient blades facilitating the production of electricity, where the area of a blade is smaller.

A third type of converter is known as DARRIEUS as shown in figure (3-24), a vertical axis construction. Their advantage is that they do not depend on the direction of the wind. To start, they need because of their low starting torque the help of a generator working as a motor or the help of a SAVONIUS rotor installed on top of the vertical.

3.12 Different Types of Wind Energy Converters
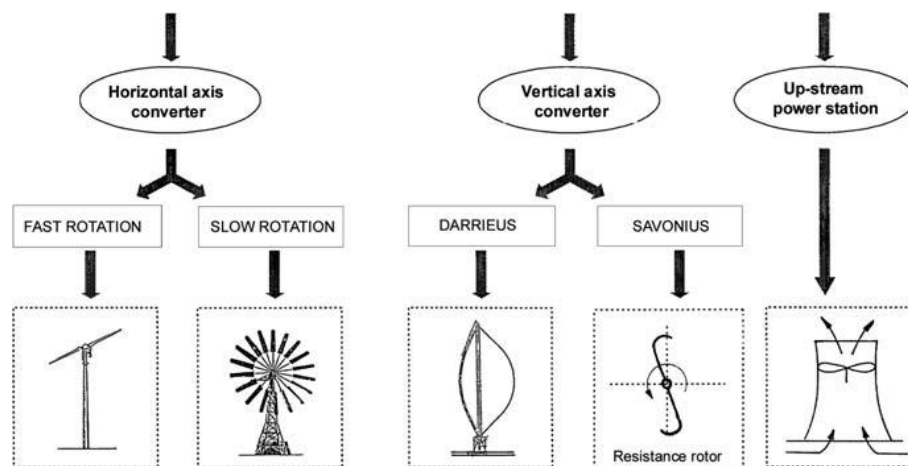
Figure (3-24) Overview of different types of wind energy converters.

(Source: Introduction to Wind Energy Systems Basics,Technology and Operation, Hermann-Josef Wagner · Jyotirmay Mathur).

A modification of the Darrieus rotor is in the form of H-rotor; there are more than 30 installations of H-rotors worldwide but all of them are below the capacity of 300 kW. Prototype testing was successfully completed for this type but the commercial stage is yet to be seen.

The SAVONIUS rotor is used as a measurement device especially for wind velocity; it is used for power production for very small capacities under 100W [21].

CHAPTER 4

USEFUL WIND ENERGY

4.1   Efficiency Varies with Wind Speed

A given wind turbine has a "design point" that generally defines its peak efficiency at the wind speed for which the system is designed. At wind speeds above and below the design speed the efficiency is the same or less - maybe much less. If a turbine's best efficiency is 40% at a wind velocity of 9 meters per second, it will be 40% only at that wind speed. At all other wind speeds it will be something worse. That wind turbine will generally operate at lower than its best efficiency, because wind speeds are never constant or average.

The electric power actually produced will be still lower because the generator efficiencies are also less than 100% (generally in the mid- or low-90's at best), and there are further losses in the conversion electronics and lines. But this is true of all power technologies. When all these losses are figured in, you might, if you are lucky, be getting 35% or so of the wind's energy actually delivered as useful electrical energy to the end user in the very best conditions. The average might only be in the twenties [29].

In reality, the power coefficient will depend on how much is lost at each stage of the energy conversion process. Some is even lost before it can begin.

4.2   Losses Add Up
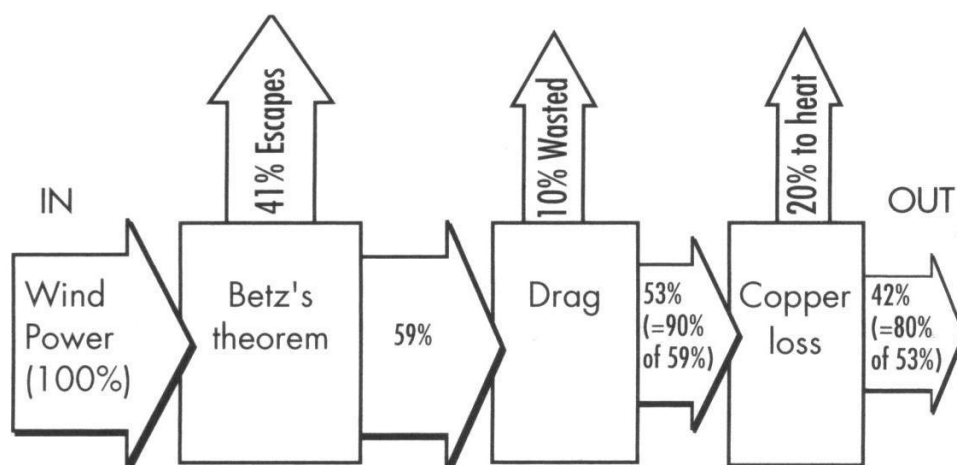
Figure (4-1) Losses Add Up.
(Source: Wind power Workshop, Hugh Piggott[28]).

4.3   Betz's Theorem

Albert Betz (1926) is credited with figuring this out, so his name is always used to refer to this theory.

In order to extract power from the wind, it must be slowed down. To remove all the wind's power would involve bringing the air to a halt. However, this would cause a pile-up of stationary air at the windmill, preventing further wind from reaching it. The air must be allowed to escape with some speed, and hence with some kinetic energy (which is lost).

According to Betz, the best power coefficient we can hope for is 59.3%, but in practice this figure will be whittled down further by other losses described next.

4.4   Drag

The rotor blades convert the energy of the wind into shaft power. Later we discuss the advantages of using a few, slender blades which rotate fast, compared with many wide blades, rotating slowly. Fast moving blades will experience aerodynamic 'drag'. Drag holds the blades back, wasting some of the power they could be catching from the wind, so we need to make the blades as 'streamlined' as possible.

Even the best designed 'airfoil section' blades will lose about 10% of the power they handle this way. Home built blades may lose a lot more.

4.5   Mechanical Friction

There will also be friction losses in the bearings, brushes and any sort of mechanical drive, such as a gearbox or pulley system. These will only increase slightly with increasing speed.

Therefore when the windmill is working hard, in a strong wind, the friction losses may be only a tiny percentage of the total power. But in light winds friction losses can make an enormous difference, especially in very small windmills, which have relatively low rotor torque.

4.6   Copper Losses

The next stage is to make electricity. This takes place in the coils of the generator. Electric current suffers from its own kind of friction, which heats the wires.

This 'friction' is in proportion to the 'resistance' of the copper wires carrying the current. You can reduce the resistance (and so the 'copper loss') by using thicker wires. This makes the generator heavier and more expensive, but it may be worth it. The resistance of a copper wire increase with rising temperature. Copper losses heat the coils, which increases temperature, thereby increasing resistance and causing more copper loss. This vicious circle can lead to burn out in the worst case, and will certainly lower the efficiency of the machine, so it will be important to look at the cooling of the generator, in the overall design. Copper losses increase with the square of current. When the generator is working at 'part load', in other words in light winds, losses in the main windings are very small. Some generators also have 'field coils' carrying an almost constant current. In light winds, they may consume all the power that blades can produce, leaving you with nothing.

Finally, do not forget about copper loss in the cable from the windmill. Where the cable is very long, it also need to be very thick.

If the cost of thick cable becomes ridiculous, then it is worth changing the system voltage. At higher voltages, less current will be needed to transmit the same amount of power. High voltage means much lower copper loss in cables, which is why it is used, in spite of the safety problems it may cause. A 12 volt system will lose 400 times as much power as a 240 volt system, when using the same cable.

4.7 Iron Losses

The fact that the flux is changing in the core all the time affects not only the coils around it, but also the steel in the core itself. We don't want these 'side-effects' in the core; they waste power. Iron losses occur for two reasons:

1- The iron is being magnetized and demagnetized at a rapid rate. This process involves hysteresis, and so takes energy. Special steels which are easily magnetized can be used to reduce hysteresis loss.
2- The flux changes tend to produce circulating currents in the steel, following any conductive path which links around the changing lines of flux. A core built from flat laminations can be used to break up any such large circuit paths, minimizing these 'eddy currents'.

4.8 Rectifier Losses

Very often, small windmills are built with permanent magnet alternators, which produce alternating current (A.C.). The power is then fed into a battery, for use as direct current (D.C.). A converter is required, which changes the A.C. into D.C. This is the 'rectifier'. Modern rectifiers are simple, cheap, reliable semiconductor devices,

based on silicon diodes. They work very well, but like everything in this world, they need their percentage. (One begins to wonder if there will be any power left at the end of all this!) In this case the rule is simple: each diode uses about 0.7 volts. In the course of passing through the rectifier, the current passes through two diodes in series, and about 1.4 volts are lost. In other words, to get 12 volts D.C. out, we need to put 13.4 volts in.

This represents another energy loss, representing about 10% of the energy passing through the rectifier. Again, changing to a higher voltage will reduce this loss. For example, in a 24 volt system the voltage lost in the rectifier will be the same as in a 12 volt system (1.4 volts), but it is now less than 5% of the total [28].

CHAPTER 5
SIMULATION AND RESULTS

5.1   The Wind (Speed and Direction) for the Gaza strip

After looking at the graphs and tables that shows the wind speed and direction in year 2003 we find that during the morning hours the wind direction is south to south-east with a speed average 2.6 m/s in Gaza city and 2.2 m/s. whereas from noon until evening the wind direction is south-west to west with an increase in wind speed in Gaza from the morning by 0.83 m/s, average wind speed was recorded at 3.69 m/s , whereas in Khanyounis the increase in wind speed is 0.55 m/s recorded an average wind speed of 2.7 m/s.

Also we take into account the highest average wind speed in both Gaza and Khanyounis was recorded at 15:00 O'clock with an average wind speed of (3.89 − 4.16 m/s) and an average direction of the wind being west.

When observing the monthly and annual wind direction in Gaza we find that the wind direction is common most months of the year, south-west, except months November and December where it was recorded as south-east to east, the average monthly wind speed was recorded from 1.94m/s to 4.44 m/s, the highest wind speed recorded as 16 m/s on 18th Dec. 2003 at 17:00 O`clock with average wind direction being south-west.

Although in Khanyounis city the common average wind direction is from south-west to south-east in an average of 2.2 m/s to 4.16 m/s, the highest wind speed recorded as 16.11 m/s on 25th Apr. 2003 at 13:00 with an average wind direction being south-west[30].

1- Studies showed that the averages of the wind speed in the Gaza Strip throughout the year are as follows:
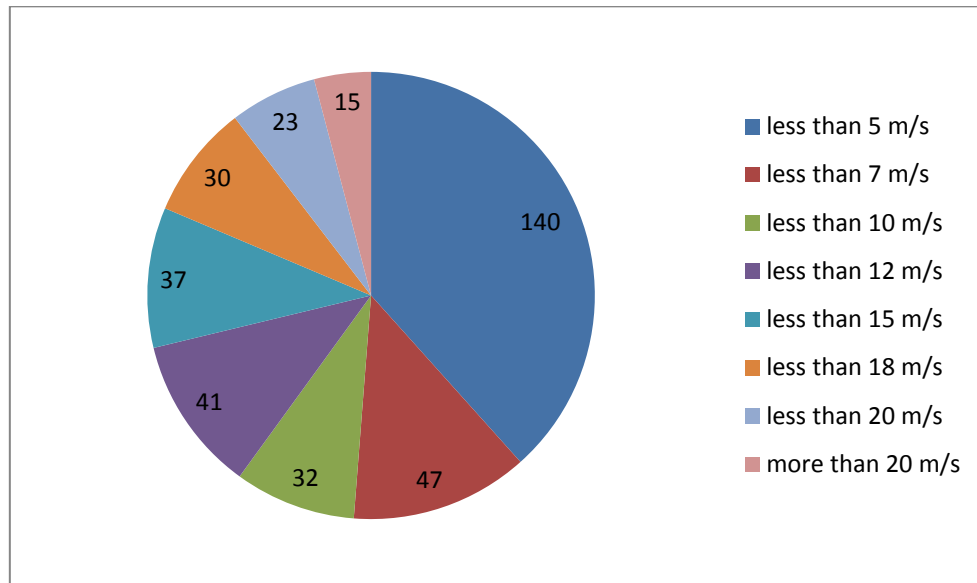
Figure (5-1) Average of wind speed in the Gaza Strip during the year.

Table 5.1 Averages of the wind speed in the Gaza Strip:

Wind Speed	Days of the year
less than 5 m/s	140
less than 7 m/s	47
less than 10 m/s	32
less than 12 m/s	41
less than 15 m/s	37
less than 18 m/s	30
less than 20 m/s	23
more than 20 m/s	15

The annual average wind speed is 19 km/h (5.278m/s), the highest average wind speed in winter reaches to 90 km/h (25m/s), and the wind direction is south-west.

If we look at the use of wind power on a commercial scale and connect it to the main electricity network, it means that we must use huge generators which need wind speed not less than 9 m/s, this wind speed is not available in the Gaza Strip 140 days or more every year (140 day less than 5m/s), which makes this non economical[30].

2- Monthly Maximum Wind Speed at 2003

Figure (5-2) shows comparison in wind speed between Gaza and Khanyounis as average wind speed in Gaza is higher than average wind speed in Khanyounis and this difference appears in January .
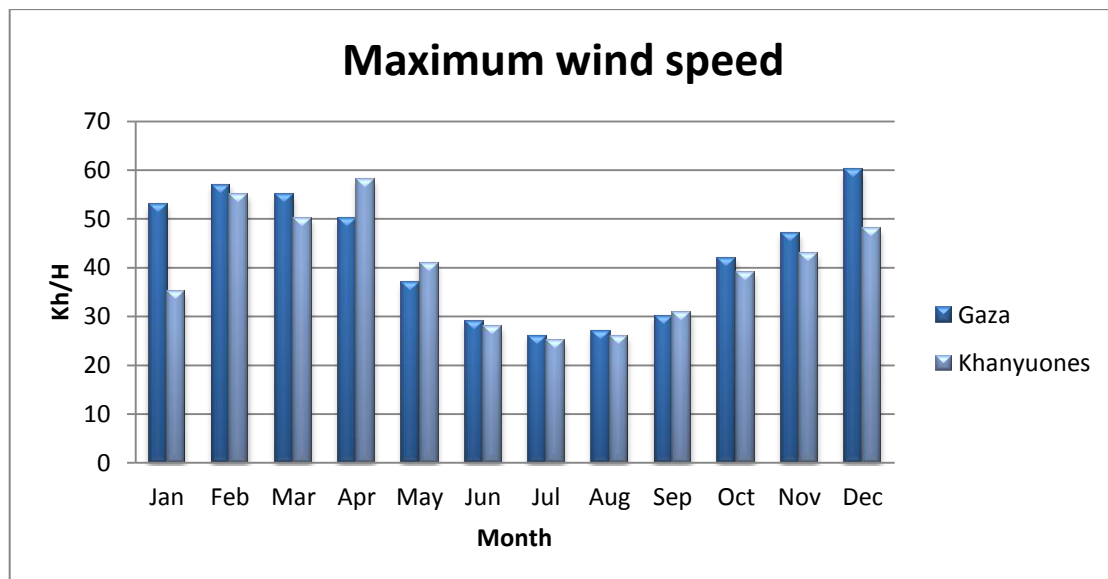
Figure (5-2) Monthly maximum wind speed in Gaza and Khanyounis at 2003.

3- Monthly Average Wind Direction and Speed in Gaza and Khanyounis
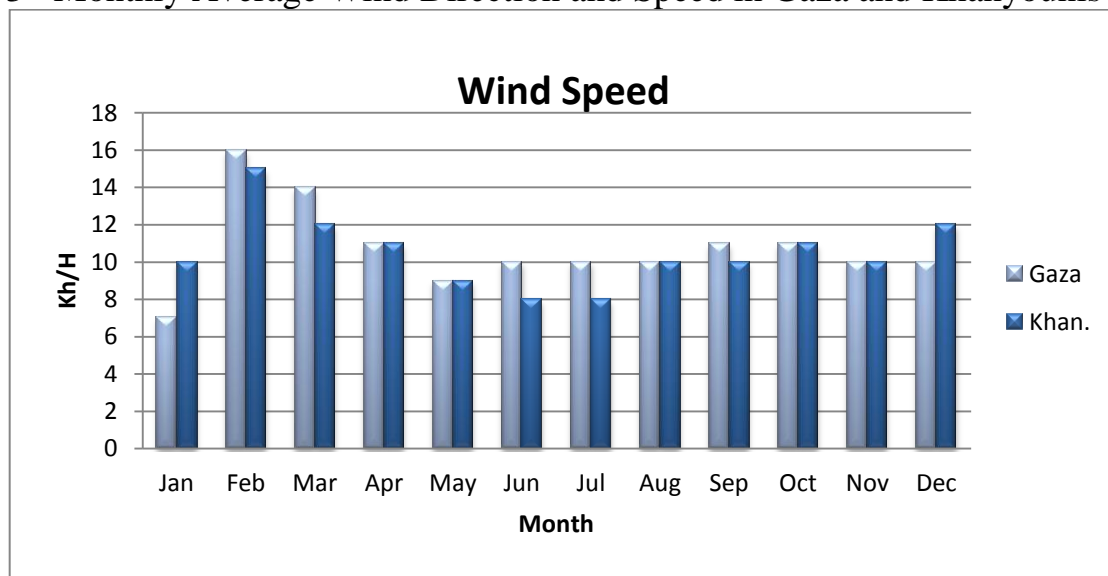
Figure (5-3)Average Monthly wind speed in Gaza and Khanyounis.
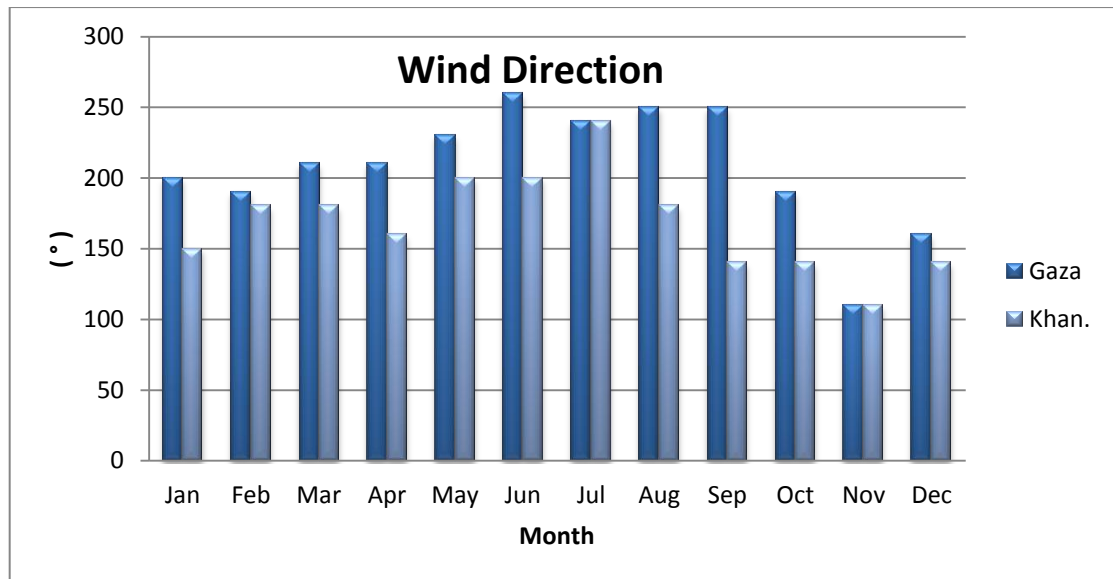
Figure (5-4) Monthly Average wind direction in Gaza and Khanyounis.

Figures (5-3), (5-4) shows that monthly average wind speed in Gaza equals average wind speed in Khanyounis with difference in monthly wind direction where in Gaza wind direction equals 208° (south-west) and in Khanyounis equals 168° (north-west).

4- Daily Average Wind Speed and Direction

Station: Gaza
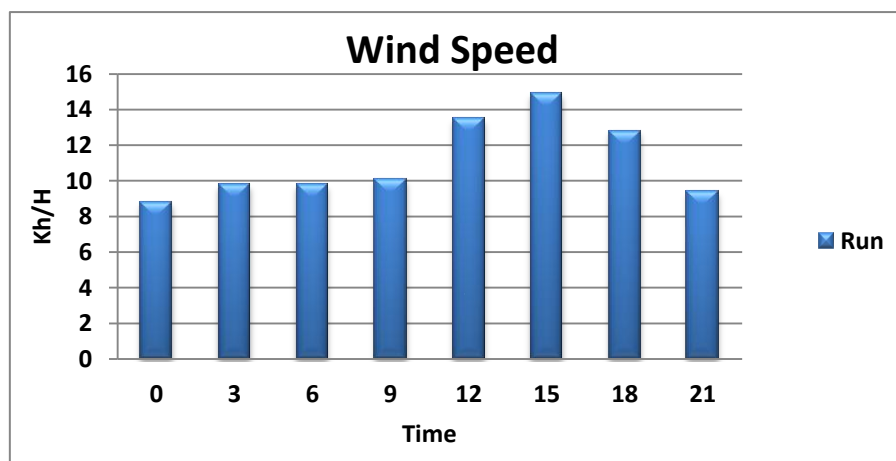
Figure (5-5) Daily average wind speed in Gaza.
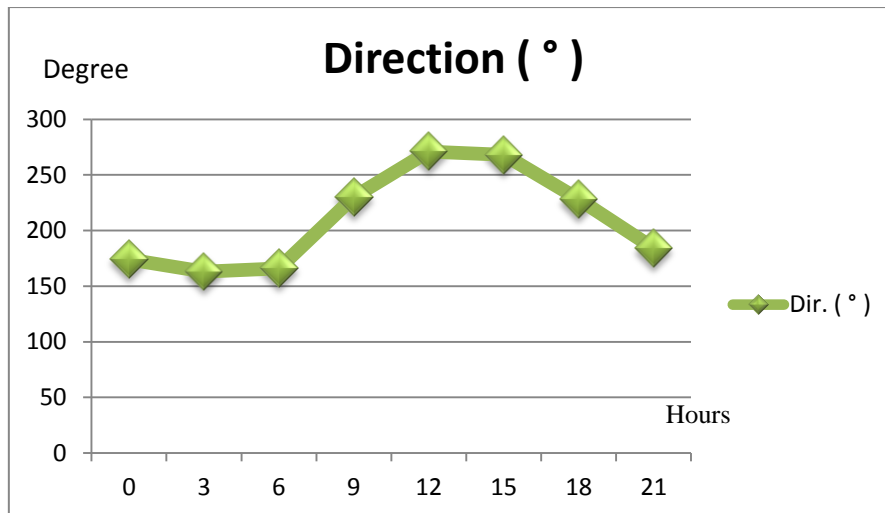
Figure (5-6) Daily average wind direction in Gaza.

Figures (5-5), (5-6) shows that daily average direction equals 233° showing that the maximum direction equals 271°(south-west) and minimum direction equals 163° (north-west), daily average speed equals 3.2m/s showing that the maximum wind speed equals 4.19Km/h (4.14m/s) and minimum wind speed equals 8.8Km/h (2.44m/s).

Station: Khanyounis
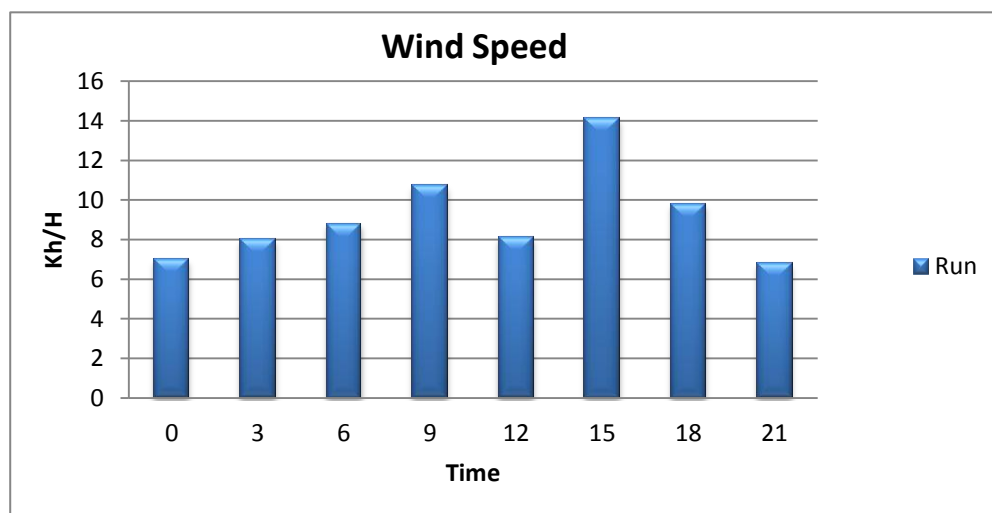
Figure (5-7) Daily average wind speed in Khanyounis.
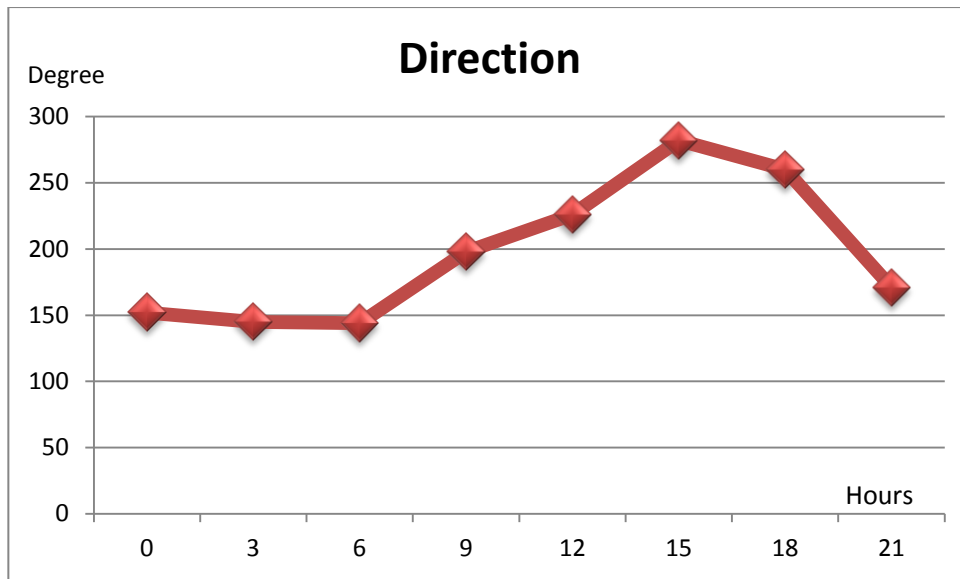
Figure (5-8) Daily average wind direction in Khanyounis.

Figures (5-7), (5-8) shows that daily average direction equals 233° showing that the maximum direction equals 282°(south-west) and minimum direction equals 144° (north-west), daily average speed equals 2.52m/s showing that the maximum wind speed equals 14.1Km/h (3.9m/s) and minimum wind speed equals 6.8Km/h (1.89m/s).

Comparing Average wind speed and direction between Gaza and Khanyounis we notice that the average direction of wind is the same. Although there is difference in average wind speed as its higher in Gaza than in Khanyounis.

5- Monthly Average and Maximum Wind Speed for year 2007 in Gaza.
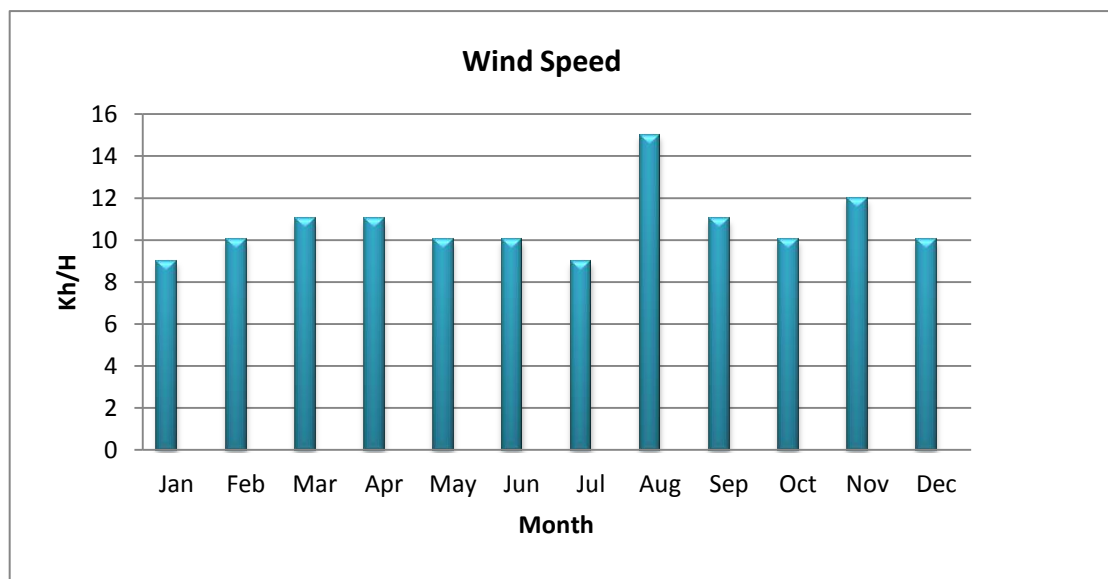
Figure (5-9) Monthly average wind speed at 2007.
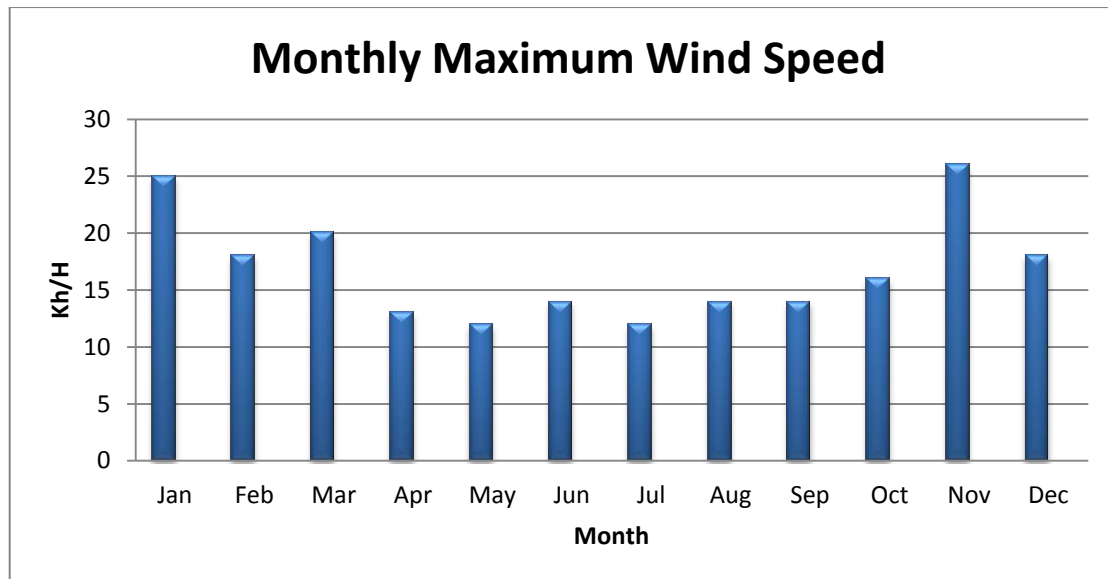
Figure (5-10) Monthly Maximum Wind Speed at 2007.

From the latest records taken from Palestine Metrological Authority to The Gaza Strip at 2007, which is the latest record in the Authority.

Figure (5-9) shows that the average wind speed during 2007 equals 3m/s. which is very law to produce electrical energy to depend on as an alternative resource(as previously mentioned).

However, Figure (5-10) shows that the maximum wind speed is able to produce limited quantities of energy to be used for houses or organizations as an alternative resource or to mix it with solar energy.

We notice that wind speed is law in the Gaza Strip as its average reaches 5m/s, and might reach to 7m/s sometimes but in small periods. Therefore, wind energy can't be relied on as an alternative resource to produce electrical energy.

As for wind direction, wind direction in the Gaza Strip is between south-west and north-west in some areas like Khanyounis, degrees appears between 208° - 168° in the strip(Records for wind direction are according to 2003).

5.2   Calculating Energy And Power

Many studies on several areas from Palestine managed to calculate the Power Density and the Energy per one meter square for a swept area.

In Nablus city at 2006 the power density per 1 m^2 was calculated to be 105.832W/m^2 and the energy per 1 m^2 equaled 972.1W/m^2, using factors: Yearly average wind speed V= 4.346 m/s, Weibull shape factor K = 1.9, Weibull scale factor C = 6 m/s and Density of air ρ= 1.21 kg/m³[31].
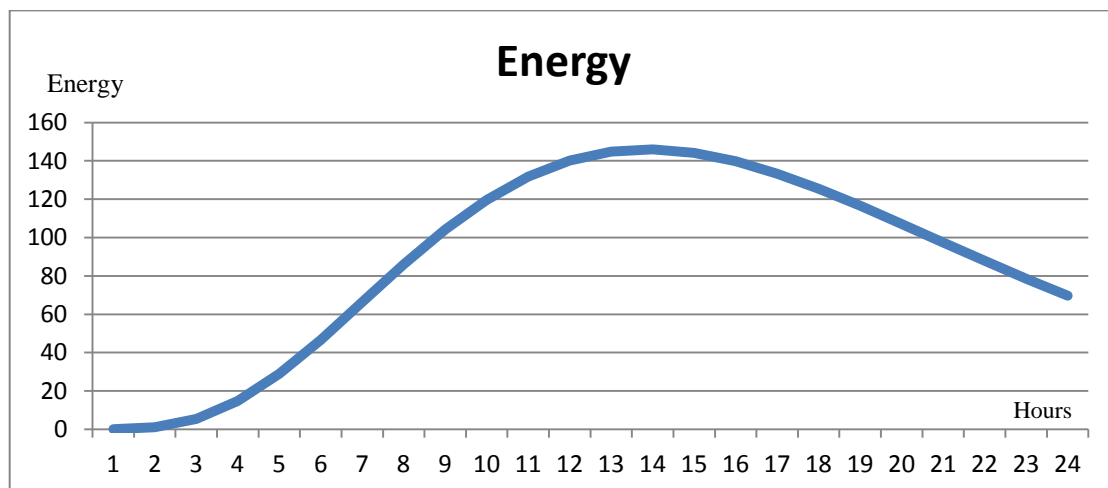
Figure (5-11) Yearly Energy distributions for Nablus site.
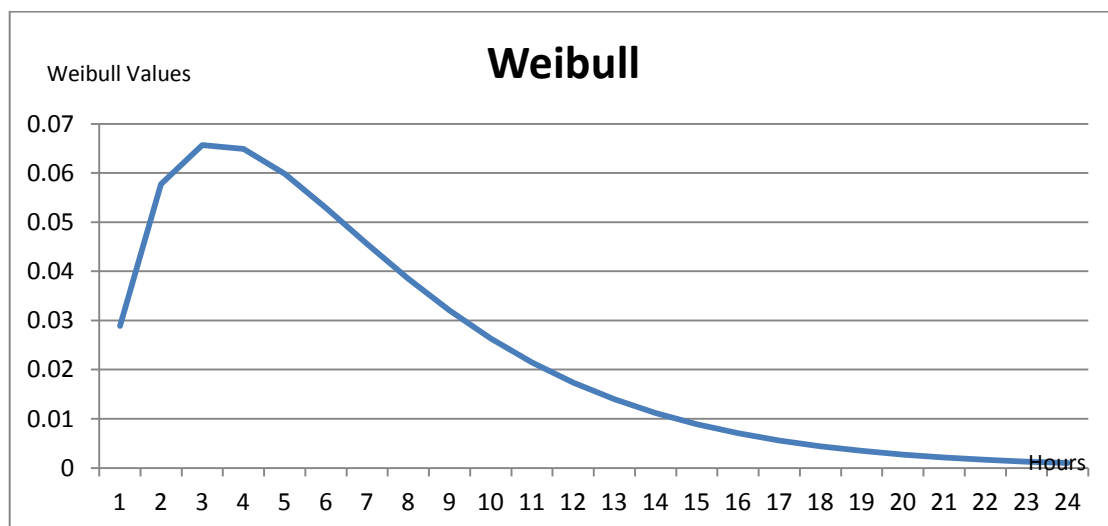
Figure (5-12) Yearly Weibull distributions for Nablus site.

In Ramallah city at 2006 the power density per 1 m^2 was calculated to be 2008.014KWh/m^2 and the energy per 1 m^2 equaled 229.22W/m^2, using factors: Yearly average wind speed V= 5.521 m/s, Weibull shape factor K = 1.81, Weibull scale factor C = 6.35 m/s and Density of air ρ = 1.21 kg/m³[31].
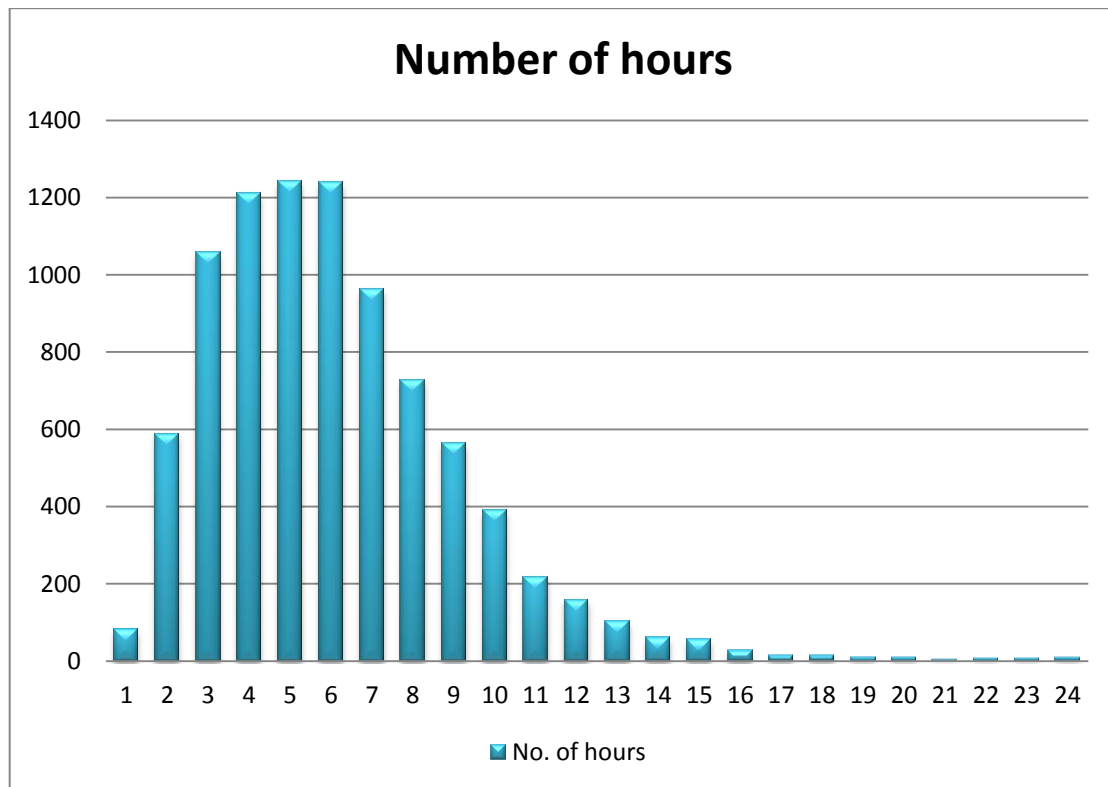
Number of hours

Figure (5-13) Number of hours per year for each wind speed range/Ramallah at 2006[14].
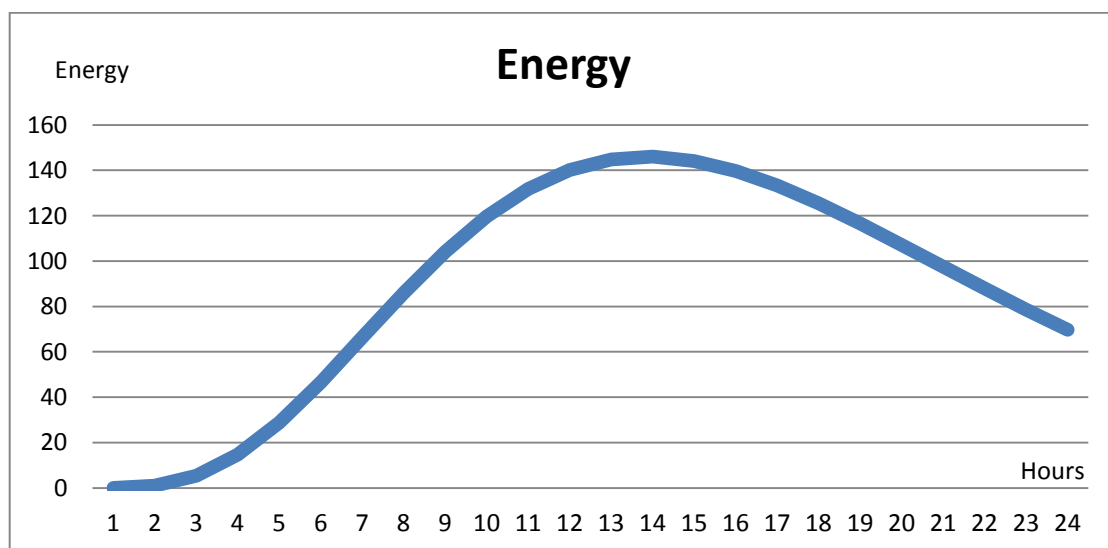
Energy

Figure (5-14): Yearly Energy distribution/Ramallah site-2006.
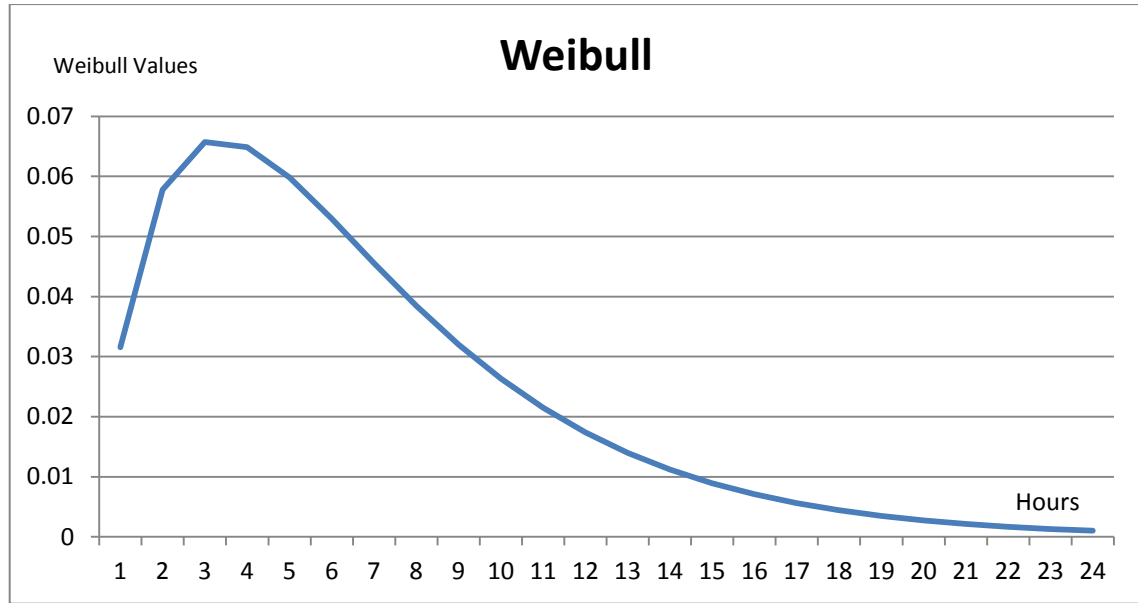
Figure (5-15) Yearly Weibull distribution/Ramallah site-2006.

5.3   Weibull for Gaza

For the Gaza Strip there are no wind speeds records since 2007 where the PCBS center was disables in the Gaza Strip, records during 2007 were only the average wind speed for each month of the year with no records for each hour of these months which increases the difficulty of drawing Weibull curve and calculating the amount of energy that can be extracted from wind energy.

As calculating the amount of wind energy requires wind speeds for each hours (which isn't obtainable) according to:

$$E = (P * \text{\# of hours}) / 1000 = KW / hr \qquad (5.1)$$

Where:

$$P = \frac{1}{2}\rho AV^3 \qquad (5.2)$$

$A=1m^2$
$\rho=1.21\text{kg/m}^3$

After solemn search, shape factor and Scale factor values were obtained through a study conducted during the 1997 by Rateb Shabana[11], which means that the Weibull curve became possible as shown in figure (5-16).

56

```matlab
clear all
close all
clc

v = [0:0.05:24];

%% wind speed distribution
%% Weibull distribution for Gaza

k = 1.455;
c = 3.182;

p = wblpdf(v,c,k);
plot(v,p)
grid on
title('Wind distribution curve for Gaza')
xlabel('Wind speed (m/s)')
ylabel('Weibull distribution')
axis([0 24 0 0.3])

%%% To verify the C, and K values we use the data of 1998 and 2004
%%% Of wind speed by Palestinian Central Bureau of Statistics, 2009.
%%% Meteorological Conditions in the Palestinian Territory Annual Report
```
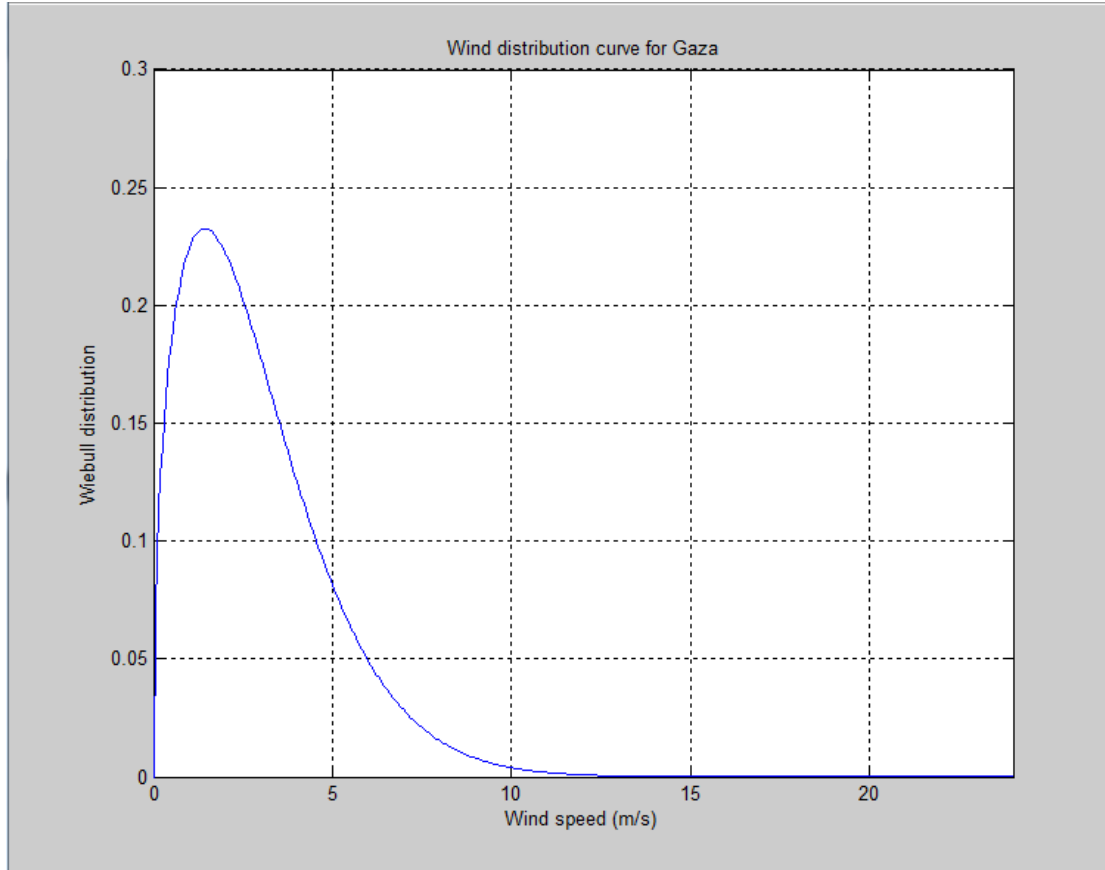
Figure (5-16) Weibull distribution curve for Gaza.

The second problem (wind speeds for each hour of 2007 was unavailable) was solved through calculating the amount of energy using Weibull curve by finding the value of the curve at each read from the wind speeds records for each month (average Monthly wind speed in 2007) and then finding The amount of energy that produced monthly from average wind speed per square meter as shown in Table 5.2.

$$E= (P*Values\ of\ Weibull*8760)/1000=Kw/hr$$

Where:

$$P = \frac{1}{2}\rho A V^3 \qquad\qquad (5.2)$$

$A=1m^2$

$\rho=1.21kg/m^3$

and 8760 are the hours of the year.

Table 5.2 Yearly wind calculations/Gaza (1998 and 2004).

Month	2004 (Km/hr)	1998 (Km/hr)	2004 (m/s)	1998 (m/s)	Average	Round 2	Generated Power (W/m^2)	Weibull Values	Energy (Kw.hr/m^2)
Jan	13	12.1	3.61	3.36	3.48	3.5	25.6	0.15	33.99
Feb	12	12.1	3.33	3.36	3.34	3.3	22.68	0.16	32.19
Mar	10	17.1	2.77	4.75	3.76	3.8	32.26	0.13	38.37
Apr	12	14.3	3.33	3.97	3.65	3.7	29.48	0.14	36.42
May	9.6	12	2.66	3.33	3	3	16.33	0.17	25.44
Jun	7.9	10.6	2.19	2.94	2.56	2.6	10.26	0.19	17.79
Jul	9.6	7	2.66	1.94	2.31	2.3	7.41	0.21	13.73
Aug	9.7	5	2.69	1.38	2.04	2	5.14	0.22	10.03
Sep	10.3	7.7	2.86	2.13	2.5	2.5	9.45	0.2	16.78
Oct	9.6	6.4	2.66	1.77	2.22	2.2	6.63	0.21	12.53
Nov	10.9	7	3.02	1.94	2.48	2.5	9.29	0.20	16.5
Dec	9.1	10	2.52	2.77	2.65	2.7	11.29	0.19	19.1
Average	10.31	10.11							**273**

Table 5.2 shows monthly average wind speed at years 2004 and 1998 in Gaza city, with an average between the two years, also shows the Generated power (W/m^2), Weibull values and energy calculated using Weibull values, as total energy equaled 273Km.hr/m^2.

5.4   Payback period

Simple Payback: The "Simple Payback" time of a project is found by taking the initial cost of putting a machine in, and dividing by the annual net income. It is a simple indicator of how long it takes to get out the money you put in[32].

Table 5.3 shows the results of payback period studies as the energy produced in the year was 273 k/w per 1 m^2 on a specific measure that cost 5,000$ per turbine comprehensive maintenance value and operating fees and appears that 139.23 is needed as a payback period.

Table 5.3 Payback period per m^2

Annual Kw.hr/m^2	273
Kw/hr Bill ($)	0.13
Annual Return ($)	35.91
Payback Period (yr) (cost 5000$/m^2)	<u>**139.23**</u>

Another study was done to the Gaza Strip through Ashdod city records for the year 2010 as Ashdod is a coastal city and its climate is similar to the Gaza Strip`s where its only 30 km away from the city of Gaza, (Using shape factor 1.455 and Scale factor of 3.182 Obtained by Rateb Shabanah 1997[11]), to find the values of Weibull curve and then found the value of the energy generated through Weibull curve and through the data of wind speeds for each hour as shown in table 5.4.

Table 5.4 Yearly wind velocity calculations using Ashdod (1997 -2010).

Mid range (m/s)	Hours	Occurrence percentage (%)	Power (W/m²)	Power density (W/m²)	Weibull values	Energy(KWh/m²) using Weibull	Energy(KWh/m²) using data
0.5	267	3.04	0.07	0.002	0.15	0.1	0.02
1.5	1760	20.09	2.04	0.41	0.16	2.92	3.59
2.5	2583	29.48	9.45	2.78	0.13	10.81	24.41
3.5	1473	16.81	25.93	4.36	0.09	21.89	38.21
4.5	1210	13.81	55.13	7.61	0.06	33.03	66.71
5.5	833	9.51	100.65	9.57	0.04	41.82	83.84
6.5	359	4.09	166.14	6.81	0.03	47.15	59.64
7.5	146	1.66	255.23	4.25	0.02	48.93	37.26
8.5	59	0.67	371.54	2.50	0.01	47.73	21.92
9.5	43	0.49	518.71	2.54	0.009	44.37	22.3
10.5	21	0.24	700.36	1.67	0.006	39.69	14.71
11.5	1	0.011	920.12	0.1	0.004	34.41	0.92
12.5	2	0.02	1181.64	0.26	0.002	29.05	2.36
13.5	3	0.03	1488.52	0.5	0.001	23.99	4.46
	8760			**43.42**	**0.75**	**425.95**	**380.38**

Table 5.4 shows the result obtained after applying wind energy equations on Ashdod records, as the power per 1 meter square was calculated to equal 43.42 W/m^2, energy was calculated using Weibull values equals 425.95 kWh/m^2 and energy was calculated using data from records equals 380.38 which is more accurate than calculated using Weibull values.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Through this study the amount of energy that can be produced per one m^2 during the year can be calculated despite the lack of data, results were achieved in two different ways, first by drawing Weibull actual curve for the strip and the second by dealing with annual wind speed records for Ashdod.

We were also able to calculate the economical payback that each m^2 produces and calculate the payback period for any project if built in the Gaza strip.

This study also showed that wind energy is reliable at the domestic level to avoid dependency of the Zionist occupation.

6.2 Recommendations

Studying the wind movement in the Gaza Strip shows that wind energy is feasible to use as a source of energy along other sources of renewable energies, but not as a primary source because running huge wind fans, ability increases to 5 MW or 10 MW, which need wind speed not less than 9 m/s, this wind speed is not available in the Gaza Strip 140 days or more every year, which makes this non economical.

But we can use wind energy in generation electricity by small turbines that do not require high wind speed which are available in many parts of the world and used in homes, control rooms, telecommunications, charging batteries, running water pump motors and running radio broadcasting stations.

Setting up a Meteorological Center for the Study of wind movement around the clock throughout the year and the modeling of technical wind maps and complete wind data.

Studying the feasibility of all types of turbines in terms of size, type, and selection of each type for a particular purpose and certain ability. Encourage investment in this field and state care for this kind of investment.

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APPENDIX A

A.1 The Maximum Wind Speed in the Gaza and Khanyounis.

Max. Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max.
Gaza Kw/h	53	57	55	50	37	29	26	27	30	42	47	60	60 km/h (16.67 m/s)
Khanyounis Kw/h	35	55	50	58	41	28	25	26	31	39	43	48	58 km/h (16.11 m/s)

A.2 Daily Wind directions in Gaza (degrees).

Month/Time	0	3	6	9	12	15	18	21	Average degree
Jan	150	160	160	180	240	240	180	160	184
Feb	200	180	180	190	230	240	190	210	217
Mar	200	190	180	220	260	270	240	190	266
Apr	200	170	190	250	280	220	200	150	256
May	160	140	160	260	290	290	210	180	257
Jun	210	160	180	280	300	310	310	250	259
Jul	170	160	170	260	290	310	260	180	245
Aug	190	170	150	270	300	320	320	220	261
Sep	160	160	150	260	300	320	300	230	261
Oct	160	160	160	240	300	280	200	160	252
Nov	130	140	150	170	25	240	150	120	169
DEC	160	160	160	180	210	180	180	160	174
Average	174	163	166	230	271	268	228	184	233

A.3 Daily Wind speed in Gaza (Km/h).

Month/Time	0	3	6	9	12	15	18	21	Average km/h
Jan	12	13	12	10	12	12	10	9	12
Feb	15	15	15	16	18	17	15	15	14
Mar	12	13	13	14	16	16	14	12	12
Apr	8	9	10	11	13	15	14	10	12
May	6	7	7	9	12	14	11	8	12
Jun	6	7	7	9	13	16	12	8	10
Jul	7	8	8	10	13	15	12	7	11
Aug	6	8	8	8	14	17	14	8	12
Sep	8	9	9	8	14	16	14	10	11
Oct	8	9	10	8	12	15	14	9	11
Nov	7	9	8	8	13	15	13	8	10
DEC	10	11	11	10	12	11	10	9	11
Average	9	10	10	10	14	15	13	9	11

A.4 Daily Wind directions in Khanyounis (degrees).

Month/Time	0	3	6	9	12	15	18	21	Average degree
Jan	135	137	140	139	184	225	251	127	167
Feb	175	172	167	170	199	238	243	178	193
Mar	169	167	157	165	210	273	276	191	201
Apr	179	158	141	157	254	279	245	161	197
May	158	136	147	254	306	303	229	177	214
Jun	171	127	142	264	304	319	298	197	228
Jul	160	149	160	262	290	312	315	190	230
Aug	133	147	133	269	300	315	334	222	232
Sep	134	134	134	234	260	320	306	201	215
Oct	154	139	139	173	168	308	240	168	186
Nov	123	133	133	143	111	282	212	111	156
Dec	137	139	139	150	131	205	171	131	150
Average	152	145	144	198	226	282	260	171	197

A.5 Daily Wind speed in Khanyounis (Km/h).

Month/Time	0	3	6	9	12	15	18	21	Average speed(km/h)
Jan	8	9	10	10	7	13	9	7	9
Feb	12	13	13	15	11	19	15	11	14
Mar	9	10	11	12	9	18	14	9	12
Apr	7	8	9	11	9	15	12	9	10
May	6	7	7	10	7	14	9	7	8
Jun	5	5	6	9	5	14	9	5	7
Jul	5	6	8	12	4	15	11	5	8
Aug	5	6	7	8	15	14	8	4	8
Sep	5	7	7	9	10	13	8	5	8
Oct	6	7	8	9	5	12	8	5	8
Nov	7	8	8	9	6	11	7	6	8
Dec	9	10	11	14	9	11	8	9	10
Average	7	8	9	11	8	14	10	7	9

A.6 Monthly Average Wind Direction and Speed in Gaza.

Gaza St.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Speed km/h	7	16	14	11	9	10	10	10	11	11	10	10	11km/h (3.056m/s)
Direction(°)	200	190	210	210	230	260	240	250	250	190	110	160	208°

A.7 Monthly Average Wind Direction and Speed in Khanyounis.

Khanyounis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Speed km/h	10	15	12	11	9	8	8	10	10	11	10	12	11km/h (3.056m/s)
Direction(°)	150	180	180	160	200	200	240	180	140	140	110	140	168°

A.8 Daily Average Wind Speed and Direction in Gaza.

Time	0	3	6	9	12	15	18	21	Average
Dir. (°)	174	163	166	230	271	268	228	184	233
Speed km/h	8.8	9.8	9.8	10.1	13.5	14.9	12.8	9.4	11.5 (3.2m/s)

A.9 Daily Average Wind Speed and Direction in Khanyounis.

Time	0	3	6	9	12	15	18	21	Average
Dir. (°)	152	145	144	198	226	282	260	171	233
Speed Km/h	7	8	8.8	10.7	8.1	14.1	9.8	6.8	9.1km/h 2.52m/s

A.10 Monthly Average Wind Speed at 2007.

Gaza St.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Speed Km/h	9	10	11	11	10	10	9	15	11	10	12	10	10.66km/h (3m/s)

A.11 Monthly Maximum Wind Speed for year 2007.

Gaza	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Max. Wind Speed(km/h)	25	18	20	13	12	14	12	14	14	16	26	18	16.83 (4.68m/s)

A.12 Yearly wind calculations/Nablus-2006[31].

Speed range (m/s)	Mid range	Duration (hours)	Occurrence percentage (%)	Power(W/m^2)	Power density(W/m^2)	Weibull values	Energy(KWh/m^2) using Weibull	Energy(KWh/m^2) using data
0—1	0.5	733.68	8.375	0.075	0.006	0.028	0.019	*0.055*
1—2	1.5	376.64	4.299	2.041	0.087	0.057	1.033	0.769
2—3	2.5	1105.78	12.62	9.453	1.193	0.065	5.4399	10.453
3—4	3.5	1786.15	20.38	25.93	5.288	0.064	14.741	46.331
4—5	4.5	1802.06	20.57	55.13	11.341	0.059	28.88	99.348
5—6	5.5	1285.92	14.67	100.65	14.775	0.052	46.649	129.437
6—7	6.5	788.24	8.99	166.148	14.95	0.045	66.294	130.964
7—8	7.5	440.14	5.024	255.234	12.824	0.038	85.994	112.338
8—9	8.5	205.65	2.347	371.545	8.722	0.032	104.178	76.4083
9—10	9.5	101.65	1.16	518.711	6.019	0.026	119.682	52.7270
10—11	10.5	55.81	0.637	700.363	4.462	0.021	131.778	39.087
11—12	11.5	25.93	0.296	920.129	2.723	0.017	140.145	23.858
12—13	12.5	9.67	0.110	1181.64	1.304	0.013	144.796	11.4264
13—14	13.5	5.17	0.059	1488.52	0.878	0.011	145.985	7.695
14—15	14.5	2.83	0.032	1844.41	0.595	0.008	144.131	5.219
15—16	15.5	8.17	0.093	2252.94	2.101	0.007	139.739	18.406
16—17	16.5	3.83	0.043	2717.73	1.188	0.005	133.345	10.408
17—18	17.5	0.83	0.009	3242.42	0.307	0.004	125.472	2.691
18—19	18.5	0.67	0.007	3830.63	0.292	0.003	116.602	2.566
19—20	19.5	0.51	0.005	4485.99	0.261	0.002	107.15	2.287
20—21	20.5	1	0.011	5212.15	0.594	0.002	97.495	5.212
21—22	21.5	7.83	0.089	6012.71	5.374	0.001	87.902	47.07
22-23	22.5	0.67	0.007	6891.32	0.527	0.001	78.602	4.617
23—24	23.5	11.17	0.127	7851.61	10.011	0.001	69.758	87.702
Sum		8760	100		105.832	1.001	2135.828	927.094

A.13 Yearly wind calculations/Ramallah-2006[31].

Speed range (m/s)	Mid range	Duration (hours)	Occurrence percentage(%)	Power(W/m^2)	Power density (W/m^2)	Weibull values	Energy (KWh/m^2) using Weibull	Energy(KWh/m^2) using data
0—1	0.5	82	0.936	0.075625	0.000707905	0.031	0.0208	0.006
1—2	1.5	589	6.723	2.041	0.137	0.057	1.03	1.202
2—3	2.5	1058	12.07	9.453	1.14	0.065	5.43	10.001
3—4	3.5	1209	13.801	25.9	3.57	0.064	14.74	31.36
4—5	4.5	1242	14.17	55.1	7.81	0.059	28.88	68.47
5—6	5.5	1240	14.15	100.6	14.24	0.052	46.64	124.8
6—7	6.5	961	10.97	166.1	18.22	0.04	66.29	159.6
7—8	7.5	728	8.31	255.2	21.21	0.038	85.99	185.81
8—9	8.5	563	6.426	371.5	23.87	0.032	104.1	209.18
9—10	9.5	390	4.452	518.7	23.09	0.026	119.6	202.29
10—11	10.5	218	2.48	700.36	17.42	0.021	131.7	152.67
11—12	11.5	159	1.815	920.12	16.71	0.017	140.14	146.3
12—13	12.5	103	1.175	1181.64	13.89	0.013	144.79	121.7
13—14	13.5	60	0.684	1488.52	10.19	0.011	145.98	89.311
14—15	14.5	56	0.639	1844.41	11.79	0.008	144.13	103.28
15—16	15.5	28	0.319	2252.9	7.201	0.007	139.73	63.08
16—17	16.5	15	0.171	2717.7	4.653	0.005	133.34	40.76
17—18	17.5	14	0.159	3242.4	5.181	0.004	125.47	45.39
18—19	18.5	10	0.114	3830.6	4.372	0.003	116.6	38.306
19—20	19.5	9	0.102	4485.9	4.608	0.002	107.15	40.37
20—21	20.5	4	0.045	5212.1	2.379	0.002	97.49	20.84
21—22	21.5	7	0.079	6012.7	4.804	0.001	87.9	42.08
22-23	22.5	7	0.079	6891.3	5.506	0.001	78.6	48.23
23—24	23.5	8	0.091	7851.6	7.170	0.001	69.75	62.81
Sum		8760	100		229.22	0.57732504	2135.8	2008