MODELING OF WIND POTENTIAL AND DESIGNING A SAVONIUS VERTICAL AXIS WIND TURBINE FOR URBAN ENVIRONMENT: NUMERICAL, EXPERIMENTAL STUDY, AND ECONOMIC ANALYSIS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
MUETAZ ALMAHDI MOHAMMED ALFALAH

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

NICOSIA, 2019

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I hereby declare that, all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Nowadays, in the rural areas of developing countries, people tend to prefer a cost-effective and low maintenance way of harnessing wind energy through the vertical axis wind turbines. Savonius vertical axis wind turbines are relatively simple to install on restricted-space locations such as the rooftop of the buildings or on top of communication towers. Therefore, the primary objective of this project is to evaluate the wind potential in five urban regions in Northern Cyprus. The Weibull distribution function is widely used in analyzing the wind potential at a specific region. In the present thesis, the analyzing of wind speed characteristics has been made and compared using Two-parameter Weibull probability distribution, and Three-parameter Weibull distribution. The monthly wind data are used and collected from the Meteorological Department of Cyprus. The results showed that Three-parameter Weibull distribution is provided the best fit to the actual wind speed data for Lefkoşa, Güzelyurt, and Gazimağusa. In addition, Two-parameter Weibull distribution is considered as the best distribution for examining the wind speed characteristics for Girne and Dipkarpaz. Moreover, a small-scale wind turbine can be used to generate electricity in these selected regions. The second objective in the current study is to introduce a new configuration of the Savonius wind rotor turbine to improve the performance of rotors and generate electricity for the small household. The experiments were conducted at wind speeds ranging from 2 to 12 m/s in front of a low-speed subsonic wind tunnel. Based on the experimental results, the newly developed Savonius-style resulted in a noticeable improvement in the power compared to that of the conventional Savonius rotors. Moreover, the results show that the long overlap significantly increases the power: by 40% compared with a short overlap. Based on the economic analysis, the results showed that LCOE for wind project was 0.085$/kWh for Gazimağusa and 0.104$/kWh for Dipkarpaz. In addition, the annual electricity exported to the grid was in the range of 1577-8410kWh.

Keywords: Cyprus; Economic analysis; New configuration of Savonius rotor; Torque; Power; Wind characteristics; Wind potential

ÖZET

Günümüzde, gelişmekte olan ülkelerin kırsal bölgelerinde, insanlar rüzgar enerjisini dikey eksenli rüzgar türbinleri aracılığıyla kullanmak için düşük maliyetli ve düşük bakım yöntemlerini tercih etme eğilimindedirler. Savonius dikey eksenli rüzgâr türbinlerinin, binaların çatısı gibi sınırlı alanlara veya iletişim kulelerinin üstüne kurulması nispeten kolaydır. Bu nedenle, bu çalışmanın temel amacı Kuzey Kıbrıs'taki beş kentsel bölgede rüzgar potansiyelini değerlendirmektir. Weibull dağılım fonksiyonu, belirli bir bölgedeki rüzgar potansiyelini analiz etmede yaygın olarak kullanılır.Bu yazıda, rüzgar hızı özelliklerinin analizi, İki Parametreli Weibull olasılık dağılımı ve Üç Parametreli Weibull dağılımı kullanılarak karşılaştırıldı. Aylık rüzgar verileri Kıbrıs Meteoroloji Bölümü'nden kullanılmakta ve toplanmaktadır. Sonuçlar, Üç parametreli Weibull dağılımının Lefkoşa, Güzelyurt ve Gazimağusa için gerçek rüzgar hızı verilerine en uygun şekilde sağlandığını gösterdi. Ayrıca, İki parametreli Weibull dağılımı, Girne ve Dipkarpaz için rüzgar hızı özelliklerini incelemek için en iyi dağıtım olarak kabul edilir. Ayrıca, bu seçilen bölgelerde elektrik üretmek için küçük ölçekli bir rüzgar türbini kullanılabilir. Bu çalışmada ikinci amaç, Savonius rüzgar rotor türbininin, rotorların performansını iyileştirmek ve küçük haneler için elektrik üretmek için yeni bir konfigürasyonunu sunmaktır. Deneyler, düşük hızlı bir ses altı rüzgar tüneli önünde 2 ila 12 m / s arasında değişen rüzgar hızlarında gerçekleştirilmiştir. Deneysel sonuçlara dayanarak, yeni geliştirilen Savonius tarzı, geleneksel Savonius rotorlarına kıyasla güçte gözle görülür bir iyileşme ile sonuçlandı. Dahası, sonuçlar uzun örtüşmenin gücü önemli ölçüde arttırdığını göstermektedir: kısa örtüşme ile karşılaştırıldığında% 40 oranında. Ekonomik analize göre, sonuçlar rüzgar projesi için LCOE Gazimağusa için 0.085 $ / kWh ve Dipkarpaz için 0.104 $ / kWh olduğunu göstermiştir. Ayrıca, şebekeye verilen yıllık elektrik 1577-8410kWh arasındaydı.

***Anahtar Kelimeler*:** Kıbrıs; Ekonomik analiz; Savonius rotorunun yeni konfigürasyonu; Tork; Güç; Rüzgar özellikleri; Rüzgar potansiyel

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LIST OF ABBREVIATIONS USED

N:	Blade number
e:	External overlap
2W:	Weibull distributions: two-parameter
3W:	Weibull distributions: three-parameter
v:	Wind speed
$\boldsymbol{f(v)}$**:**	Probability density
$\boldsymbol{F(v)}$**:**	Cumulative distribution
c:	Scale parameter
k:	Shape factor
γ:	Location parameter.
$\overline{\boldsymbol{P}}$**:**	Available power for wind per unit area
ρ:	The density of air
α:	Surface roughness coefficient
$\boldsymbol{L'}$**:**	Overlap ratio
D:	Blade diameter
RPM:	Rotational speed
$\boldsymbol{P_m}$**:**	The mechanical power
$\boldsymbol{P_e}$**:**	Electrical power
$\boldsymbol{P_r}$**:**	Power of wind turbine
$\boldsymbol{C_p}$**:**	Performance coefficient
CF:	Capacity factor
EP:	Energy production

CHAPTER 1
INTRODUCTION

1.1 Background

The global energy demand is rapidly increased because of the consumption of fossil fuel. Therefore, the increases of energy demand have increased in recent years the significance of renewable energy as an alternative source to reduce greenhouse gas emissions (GHG). The increases of populations and energy demand have increased in recent years the significance of renewable energy as an alternative source. Renewable energy sources are considered clean alternatives to fossil fuels that can provide sustainable energy (Hu X et al.,2013;Noorollahi Y et al.,2016). Renewable energies such as wind energy are recognized as alternative resources for generating electricity in the future (Dai et al., 2017).A key advantage of wind energy is that they avoid carbon dioxide emissions (Katinas et al., 2017).It now used extensively for meeting the electricity demand in many countries such as India (Katinas et al., 2017)., (Rocha et al., 2012; Chang., 2011), Turkey (Noorollahi et al., 2016). And Saudi Arabia (Kamoji et al., 2009; Gupta & Biswas., 2011). A wind speed characteristic is the most factors to investigate the wind potential at a specific location (Golecha et al., 2011; Roy & Ducoin., 2016), Several scientific researchers have been investigated the wind potential in different regions. For instance, (Goodarzi & Keimanesh., 2015; Menet., 2004).evaluate the wind potential and estimate the electricity cost per kWh using small-scale vertical axis wind turbine at eight selected regions in Northern Cyprus.The results showed that Aeolos-V2 with a rating of 5kWuse could be suitable for generating electricity in the studied locations. (Kamoji et al., 2009; Jian et al., 2012) evaluated the economic feasibility of 12MW grid-connected wind farms and PV plants for producing electricity in Girne and Lefkoşa in Northern Cyprus. The authors concluded that PV plants are the most economical option compared to wind farms for generating electricity in the studied regions. (Azad et al., 2014) investigated the wind energy assessment at different hub heights in desired locations using the Weibull distribution function. The results showed that the wind power sources in the site are categorized as poor. (Albani & Ibrahim., 2017) analyzed the wind energy potential at three coastal locations in Malaysia. They concluded that the production of wind energy is only feasible and practical at certain locations in Malaysia. (Shoaib et al., 2019) analyzed the wind power potential in Jhampir, Pakistan using Weibull distribution function. They observed that Jhampir is a suitable site for developing the wind power plant. (Gul et al.,2019) investigated the wind potential at Hyderabad, Southeastern province in Pakistan using Weibull and Rayleigh distribution functions. They found that this region is suitable to generate electricity for the local communities.

Generally, wind energy can be converted directly into electricity using wind turbines. Horizontal axis wind turbines are commonly used in energy production for grid-connected large utilities whereas vertical axis types are preferred for use in small scale domestic applications. Throughout the years, researchers have given a lot of attention to the horizontal axis wind turbine with outstanding achievements in terms of further developing the technology. On the other hand, current conventional designs for the vertical axis wind turbine do not satisfactorily meet the requirements of users in cases of off-grid power generation at low wind speeds. Therefore, investigation of small-scale turbines for distributed energy systems has become popular (Saeidi et al., 2013; Balduzzi et al., 2012; Chong et al.,, 2013). The Savonius-style wind turbine has the potential to fulfill the needs of users for such conditions. It has been reported that this type of wind turbine has a lower efficiency when compared to its rivals. Nevertheless, Savonius-style wind turbines distinguish themselves from the other types targeting such markets because of its following advantages: (1) plain design which simplifies the manufacturing and maintenance processes and thus renders them to be more reliable devices;(2) low cut in and operating speeds which lead to lesser noise, wear and tear;(3) they can be installed on restricted-space locations such as rooftops, buildings or on top of communication towers; and (4) there is no need for yaw mechanism since they operate independently from the wind direction (Roy & Saha.,2013; Abraham et al., 2012; Akwa et al., 2012).

1.2 Research Goals

The objectives of this study can be divided into

1) As a continuation of authors studies on wind potential in Northern Cyprus (Alayat et al., 2018; Kassem et al., 2018; Kassem et al., 2019), the primary objective of this work is to evaluate the available wind energy at five selected locations in Northern Cyprus using Three-parameter Weibull probability distribution that may better correspond to the lower speed wind data and give more appropriate results. Then, the study is compared to the evaluation of wind potential in Northern Cyprus using Two-parameter Weibull probability distribution with the Three-parameter Weibull probability distribution. Kolmogorov–Smirnov (KS) statistic is determined to evaluate the best distribution that fit the actual wind speed. The data consisted of hourly, monthly wind speed and wind direction during a period of 6-years (2010-2016). The data were collected from the Meteorological Department located in Lefkoşa and measured at 10m height.

2) The second objective of the study is to verify the performance of wind energy potential to show that vertical axis wind turbine is most suitable to generate electricity in Northern Cyprus. Therefore, the second objective of the current study is to design a new configuration Savonius wind turbine that can be used to meet the power for low demand applications. The goal of the present study is to investigate experimentally the effects of the blade geometry, blade number (N) and external overlap (e) on the performance of new Savonius-style wind turbine. To ensure that the measurements of the current experimental setup are reliable, the experimentally obtained mechanical power data of the conventional Savonius type wind turbine are compared to those of an identical wind turbine from the literature. In this research, an innovative Savonius-style wind rotor is designed to produce power for electricity demand in small buildings. This design is simple and cheap.The flowchart in Figure 1.1 illustrates the analysis procedure of this study.

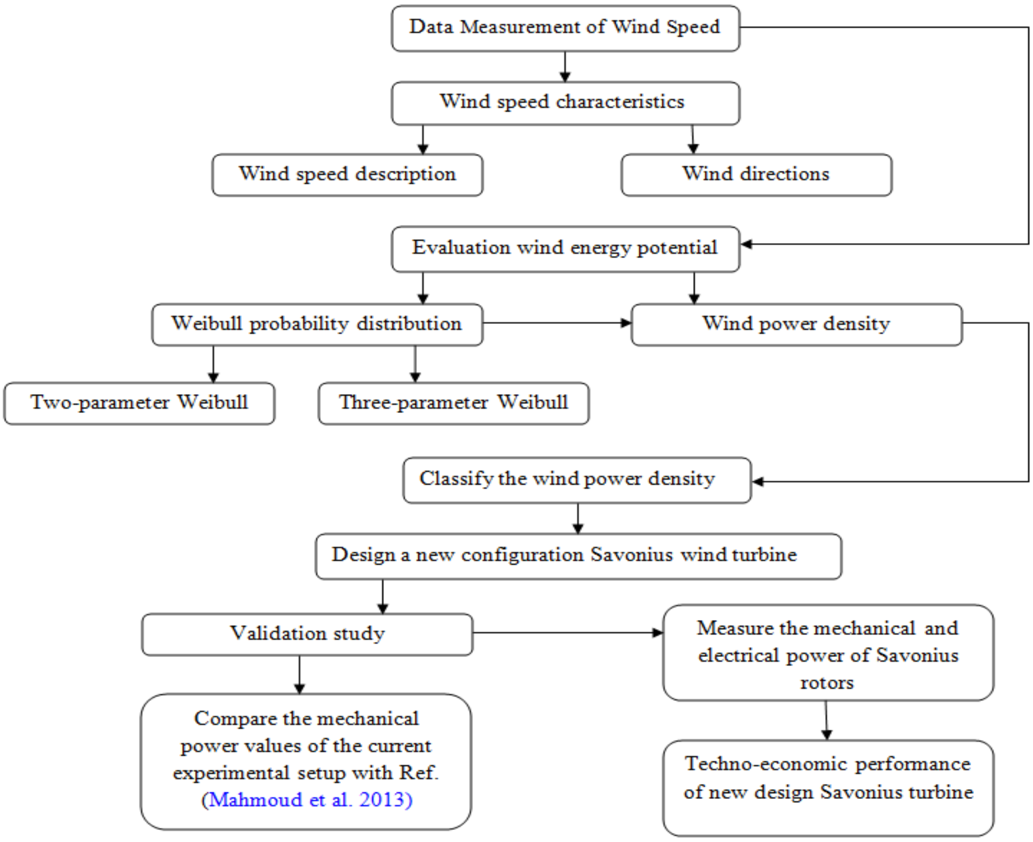


Figure 1.1: Flowchart of the analysis procedure of the present study

1.3 Research Outline

This chapter presents an introduction to wind energy, its importance and the potential for reducing environmental pollution caused by the use of fossil stone. In Chapter 2, the background of wind turbines is explained in detail, followed by the history of wind turbines and the discussion of turbine type also potential wind energy. Chapter III The background presentation of the Savonius wind turbines which are the main subject of this work illustrates Chapter 4 designed and the method of measuring the constant torque and mechanical force of the rotor. In Chapter 5 all test results are displayed for a new configuration of small Savonius rotors. On the end of the dissertation, the conclusions are presented in Chapter 6.

CHAPTER 2
WIND ENERGY AND WIND TURBINE FUNDAMENTAL

This chapter briefly discusses wind energy possibilities and explores the strengths and weaknesses for wind energy, the wind turbines, also known as wind energy converters and the various types of wind turbines. We also demonstrated the type and advantages of vertical and horizontal wind turbines.

2.1 History of Wind energy

Wind energy is considered a type of solar power. This energy (also known as wind power) illustrates the mechanism by which wind is utilized in generating electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. An electrical generator on the other hand has the capability of converting mechanical power into electricity. This mechanical energy is then used in particular areas, for example water pumps.

There are a numbers of reasons which causes the wind. One reason is assigned to the thermal heat radiating by the sun, which is then heated in the atmosphere in an unevenly manner. Another is because the earth rotates around its own axis. And the discrepancy in the levels of the earth also causes the wind. Mountains, lakes, river, and plants have an effect on the flow forms of the wind. Another way of converting wind into electricity is through the stator. The stator is a stationary device made up of coils of wire and is part of a rotary system which can be found in electric generators. The process works by moving magnets on the stator. This is AC electricity. Later it is changed to DC electricity which can be found in batteries or electricity power grids. These power grids have triggered enormous research in the field of wind turbine technology. A centerpiece of this interest revolves around Sigurd Savonius, who was a Finnish inventor who is credited with the Savonius wind rotor. Developed in 1925, this rotor is considered by far the easiest and most inexpensive vertical axis of wind energy converters.

It boasts great initial features which include high starting torque and comparatively low control speeds. This converter can take wind in many ways and methods. There have been a great number of applications for this device but the biggest disadvantage remains is the converter's poor efficiency in aerodynamic performance when compared to other converters. (Youssef Kassem & Hüseyin Çamur., 2017).

There has been some serious effort to explore the aerodynamic features and the influence of geometric design patterns in the Savonius converter and it's a critical issue that's not usually easily solved or calculated and is necessary to be done. The two coefficients namely the drag and torque can attain the maximum at 0° for the drag angle and 30° rotor blade for the torque angle. Mohammed performed an experimental study mainly taking subsonic wind tunnel with low wind speed and relative to the performance of the two others. It was done to make a comparison between the two and three blades of the Savonius wind convertor machine.

The outcome of the study demonstrated that a rise in the amount of blades consequently causes a rise in the drag surfaces on the wind flow which prompts it to raise the reverse torque for extra power. This outcome provokes a drop by a drastic amount in the value known as net torque of the Savonius wind convertor. (Ali., 2013).After mentioned all the previous in the figures details about wind energy, we will mention here the strengths and weaknesses of wind power:

2.1.1 Advantages of Wind Energy

Capacity to decrease financial risks

A renewable energy contract is able to decrease your financial risks:

- Depend on non-volatile energy prices.
- Diversification in renewable energy can mitigate and decrease price risk of fossil fuels.
- Assist in protecting your company from possible regulations that work against fossil fuels industry.

Reduce Your Carbon Footprint

- Governments and companies are decarbonizing and getting rid of carbon emissions. By choosing the right and suitable renewable energy, businesses are able to solve environmental challenges with carbon emissions, adhere to the sustainability goals and demonstrate the responsibility to projects such as the Sustainable Development Goals, Science-Based Targets Initiative and RE100 and CDP, formerly the Carbon and Disclosure Project.

2.1.2 Disadvantages of Wind Energy

Wind is inconsistent

- Wind energy has many things in common with solar energy if you talk about it in terms of consistency. Even though wind energy is considered a suitable renewable resource, the speed of the wind changes dramatically each day. This makes it a frustration for the developers of wind converters.

- Requires lofty amounts of deposits for financing.
- Although many attempts were taken to reduce the cost of wind turbine installations, it is still expensive. If the location and spot is found to be ideal. The whole operation contributes to the cost of establishing and setting up a wind turbine.
- Sound disruptions.
- The most infamous of the weaknesses of these converters is the noise they make. It is considered noise pollution. One turbine is capable of making a sound disruption, when grouped together with a large number of them, the noise grows intolerable.

These points provide a glimpse on why people oppose establishing wind converters in their neighborhoods.

2.2 Wind Energy Potential

In the 19th century potential energy was first defined by the British mechanical engineer William Rankine. His theory proposed that it starts as stored energy which can be converted into work.

The potential energy for wind power is defined as the quantity of usable energy which can be generated by wind currents. This is then changed to kinetic power by a number of devices, for example windmills, wind converters and sea vessels that use the wind. Humans have been taking advantage of this renewable energy since a very long time ago, and this can be seen in the construction of windmills, using the wind in sea navigation, and today in terms of electrical power. The unit for energy is in Joules. A joule can convert watt per second for work. The basic theory that a certain speed of wind can create enough work to complete tasks. For example, if a stable gentle wind moves the blades of a wind converter at 10 revolutions per second, and each revolution can be produced then 1.5 joules, this means that the outcome of this power will equal 15 joules. Meaning 15 watt is produced per second.

2.2.1 Wind Energy Potential in the world

In Algeria located in the northern Sahara has Statistical examination of the data for 21 stations spread in different topographic places in Algeria there have been performed and analyzed with establishing the daily and yearly variations of wind speed alternately. The Weibull parameters and density to the power of the stations were measured with the hybrid Weibull distribution. This is what Algeria uses. Finally, the obtained wind speed in Algeria proves that it is fascinating to establish a precise way of some sort of wind systems for agricultural applications (Merzouk., 2000). Jordan enjoys a number of specific places where there is a great wind potential in terms of economic electricity generated by wind. The study explored four of these places thoroughly to see if it is feasible to establish and invest 100 MW wind converters in every one of these four places. The recommended wind turbines to be established in each of the before places are considered or chosen from the international rating and specification catalogues of wind turbine manufacturers (Alsaad., 2013). We researched the study of 17 synoptic sites placed on the whole areas most commonly of Tunisia. The meteorological data gathered by professors of the Meteorology National Institute (INM), two statistical methods (meteorological and Weibull) where used to assess the wind speed characteristics and the wind energy potential taken at a high of 10 meters above the ground level and in open locations. In addition, extrapolation of these features including the height is also performed. (Elamouri & Amar., 2008).

In Nigeria due to its location wind energy is nearly not available. Three primary explanations for why these are responsible. The first explanation proposes that when compared internationally with other regions of the world, the mean wind speeds in West Africa have been stated to be far below standard of other nations. The second explanation states that fossil fuel is the main source and widely available in the country so wind energy isn't needed as much. The last primary explanation states that a large proportion of electricity is run by hydroelectric plants. It is known that various stationary (non-vehicular) agricultural tasks can be used to use wind energy. The main applications of wind power in agriculture are generally used by power supply (Adekoya& Adewale., 1992).

In Malaysia the most powerful wind only happens on the East coast of Peninsular Malaysia during the Northeast monsoon. The highest speeds happen mostly in afternoon and minimum speeds happen even of there no sunrise, a system governed by convection in the surface boundary layer as the ground is heated by the natural light in the mornings and cooled by radiation in the evenings. Is an important role in creating the possible potency. The analysis indicates that applications involving small wind machines is best and also is to generate electrical power on the comparatively underdeveloped areas in East coast of Peninsular Malaysia and most coastal areas islands which aren't linked to the national grid (Othman et al.,1993). Seven locations where selected for this experiment, namely, Gujranwala, Islamabad Capital Territory, Jhimpir, Kati Bandar, Khanewal, Multan and Sialkot in Pakistan. Wind speeds were recorded and grouped over a period of 2005–2016 and measured at 10 m height. In this study, the functions where over ten distributions were administered for analysis of the wind speed features of these specific locations and wind energy was estimated. The analysis result of the wind power and energy density as functions of tower height shows that higher tower height with high production of wind power and energy density. Therefore, it is concluded that the wind power density values in the locations (Gujranwala, Islamabad Capital Territory, Khanewal, Multan, and Sialkot) are substantial and can be used in a smaller scale kind of wind turbines for generating electricity (Khan et al.,2018).

2.2.2 Wind Energy Potential in northern Cyprus

As we know, wind power is one of the most promising renewables in most of the world as an alternative to fossil fuels. In assessing wind power for a region, the use of the Weibull distribution for the two teachers is an important tool. In some studies, particularly in this study, the characteristics and potential of wind power were analyzed in six different locations in Northern Cyprus, namely, Ercan, Famagusta and Risocarpaso, and the statistics of Kyrenia, Moravo and Nicosia. For this purpose, wind speed data, wind statistics collected in the regions were evaluated for one year between January and December 2016. The average annual wind speed was between 2.47 and 4.58 m / s. annually Seasonal parameters for Weibull distribution were obtained at different heights (45, 55 and 60 m) by reading 10 meters data at all locations. In addition, annual and seasonal wind power values were calculated for each elevation. In this study, economic assessments were conducted to determine the method of estimating the present value (PVC) of the island's winds. Assessments used to extrapolate 10-meter wind-level data for wind turbine properties and characteristics were developed in five wind conversion systems ranging from 20 kW to 800 kW. The results showed that the capacity factors for all turbines at specific locations ranged between 1.1% and 10.77%. The average minimum cost per kWh in Rizocarpaso was obtained at $ 0.00183 per hour with Enercon 33 while the average cost per unit was $ 3.304 per kilowatt-hour with GEV-MP in Kyrenia (Kassem et al., 2017). The meteorological data, which lasted more than seven years in the Salamis region, Northern Cyprus, was analyzed for a period of 7 years starting from 2009 and ending in 2016 at an altitude of 10 meters above the ground, and an analysis of the wind features was performed under the Weibull distribution theory. Accordingly, the yearly values of Weibull and k were 9.008 and 3.127 m/s, respectively. The mean energy density was 16.724W / m2. The energy theory was facilitated to measure the average yearly and monthly velocity of the wind through different altitudes. The summary of the study demonstrates that the density of this wind energy measured in this area is fit to be consumed and used by the small-scale wind converters. In addition, the theory was further economically analyzed by the current cost method PVC. (Alayat et al., 2018)

2.2.3 Wind Energy Future Potential

The increasingly high consumption frequency of the fossils energy coupled with the high demand is forcing developments and changes in the area of renewable energy. Furthermore, the inflated emissions figures caused by fossil fuels are considered a great problem of security in the world. As a result a number of nations have begun scrutinizing wind converters and their systems. (Kaygusuz et al., 2012).
A type such promising VAWT design for distributed systems is one of the techniques known as the Savonius rotor, categorized as a device that’s drag driven. The Savonius rotor asserts a lot of beneficial technological strengths including:

- Easy design that’s direct drive, and lacks the need for a gearbox.
- Entry is easy to the generator, which its bottom is positioned at the tower, which equals simpler preservation.
- Economical assuring to generate.
- Strong torque even with slow wind speed.
- Direction is not so important for wind direction, i.e., no need for yaw.
- Less noisy.

2.3 TURBINES

The term “turbine” generally refers to any device that is capable of extracting mechanical power from a fluid and transforming it to rotating energy of a turbine where, Turbines also called converters that operate by liquids are refer to hydraulic turbines, while those that uses gas are called “wind converters”, “gas converters” or “steam converters”.

Figure 2.1: Wind turbine

2.3.1 Historical Development of Wind Turbine

The use of wind for grinding grains, sailboats, and pumping water began over 3000 years ago. Windmills were an important part of life for many coming beginning around 1200BC (Mauricio et al., 2009).Wind power was broadly accessible and not being limited to the bank of flowing streams or later requiring sources of fuel. Wind power has found new application with the development of electric power in lightening building remote from centrally generated energy. Hammurabi, the famous king of the Babylonian empire is thought to have had goals for establishing an irrigation project and using wind energy in the seventeenth century BC. (Mathew et al., 2006).The oldest known form of a wind-driven wheel to energize a machine was from an engineer Heron of Alexandria in 1st century AD Roman Egypt (Sopian et al., 1995).In china the prayer wheel was used, Tibet and ancient India all the way back from the 4th century was one more old illustration of wind driven wheel.

2.4 TYPE OF WIND TURBINES

Wind converters are machines figured to transform kinetic power of the wind into electrical power; they operate by using the kinetic power generated by the wind in motion by pushing the turbine blades and spin a motor that transforms the kinetic energy into useful electric power. Before the 26th century, wind turbines were used for such operation grinding, irrigation and sailing the use of wind machine to generate electricity began in early 20th century. Wind turbines evolve from classical wind mind. They are designed to reduce the dependence of fossil duels (Wu et al., 2011).

Figure 2.2: Wind Turbines Type

2.4.1 Horizontal Axis Wind Turbine

Horizontal axis wind turbine contain in them a gearbox, rotor shaft and the assembly break have the primary rotor shaft and generates a position at the peak of a tower and is required to be facing towards the wind. Small converters are directed by means easy wind vanes, while large ones use a wind sensor grouped with a yaw system. Most horizontal wind turbines contain a gearbox which turns the low rotation of the blades into a faster to provide a rotation that is more suitable to drives on electrical generator (Hau., 2013). In some designs a different type of generator intended to slow rational speed input is used. Here, a gearbox is not needed, these designs are referred to the direct-drive, and in other words, they merge the rotor directly to the generator with no gearbox separating them. One advantage of gearless generator over gearbox generators is absence of gear-speed increaser which is susceptible to significant accumulated fatigue torque loading, related liability issues, and preservation costs (Bywaters et al., 2007).

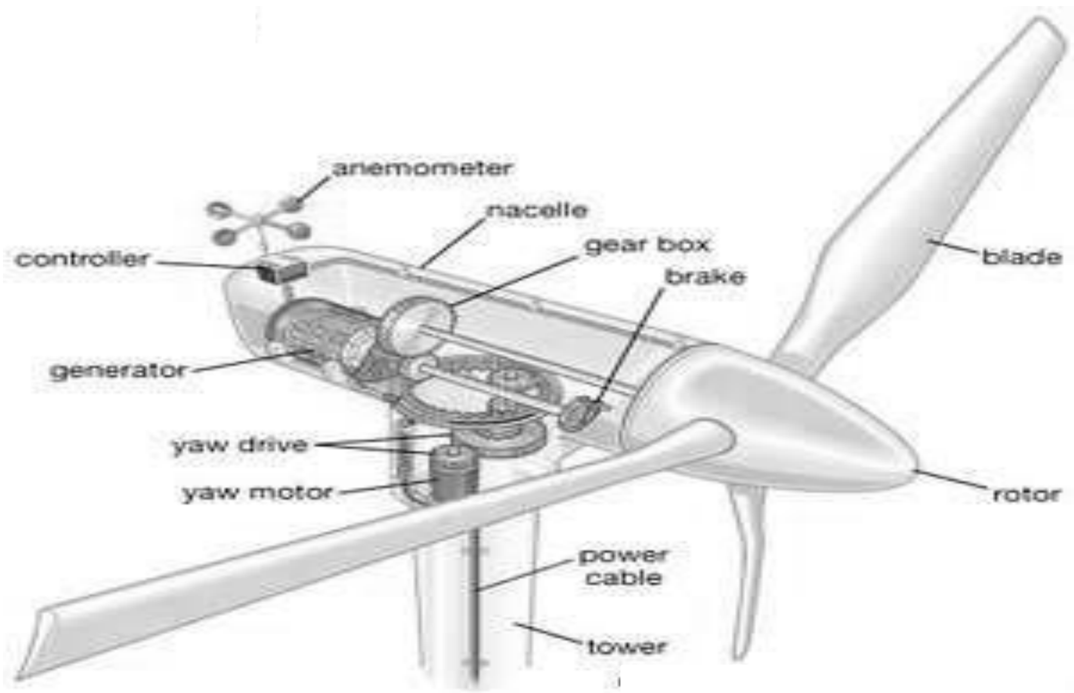


Figure 2.3: Components of a horizontal-axis wind turbine

The majority of horizontal axis turbines are designed with their rotors placed on the up-winds part of the supporting tower; the downwind design does not require or need an additional mechanism for keeping the wind in line. The blades of downwind version can have high bend in the wind to reduce their sweeping distance and wind resistance. Although the downside version possesses much strength, the up-winds are more prepared. This is largely related to the changes in weight loads from the wind because any passing blade next to the supporting tower has the possibility of damaging the turbines. Three-bladed turbines are the most widely used designs in wind farms for commercial production of electric power.

2.4.1.1 ADVANTAGES OF HAWT

- In areas with shear, the tall tower base make HAWT accessible to stronger winds, in some wind shear sites, every ten meters up wind speed can grow by 20% and power output by 34%.
- The ability of HAWTS blade to proceed in a perpendicular manner to the wind in order to receive power through whole rotation makes it highly efficient.

2.4.1.2 DISADVANTAGES OF HAWT

- High construction and installation cost. Large machinery is needed.
- Large tower manufacturing is a necessity for holding the heavy blades, gearboxes and generators.
- Laborious to lift devices namely the gearbox, rotor shaft and brake into their respected places.
- Disruption of appearance of landscape due to their height. This sometimes creates local opposition.
- An extra Yaw control process is required to turn the blade toward the wind.
- This design requires a braking Yawing machine to prevent it from spinning and injuring in high winds.
- Cyclic stress and vibration could lead to cyclic twisting which is capable of quickly damaging and hurting the blade roots, hub and axle of the turbine.

2.4.2 VERTICAL-AXIS WIND TURBINES (or VAWTS)

Vertical axis wind turbine is turbine whose axis of rotation is vertically positioned to the ground. In vertical axis wind turbine, the main rotor shaft is put in a vertical manner. Contrary to horizontal axis design, VAWT lacks the necessity of being directed toward the wind for adequate effectiveness, this is strength especially in areas where the way of the wind is largely changeable. It is also very efficient when added into a structure because it is potentially with low ability to be steered. Furthermore, the generator and gearbox should be put close to the ground using a direct drive from the rotor assembly to the nearest based gearbox. This improves the ease of fixing; one major drawback about the design is that it produces much low amounts of power on average in a given point of time. (Scott et al., 2014).

Figure 2.4: Vertical-axis wind turbines

When a converter is installed on the peak of the construction redirect wind over the top. This redirection helps in doubling the wind speed at the converter.

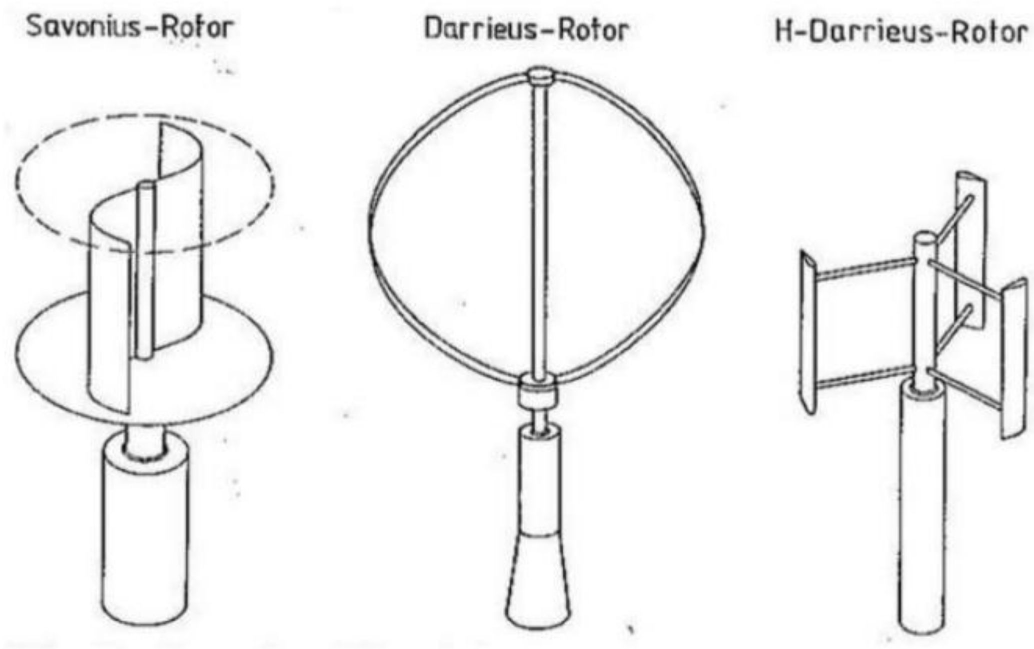


Figure 2.5: Types of VAWTs

2.4.2.1 ADVANTAGES OF VAWT

- VAWT are capable of producing electrical power in all directions of the wind (see Figures 2.5 and 2.6).
- Cost of production is comparatively lower compare to horizontal axis wind converters.
- VAWT is easy to install ate as compare to other wind turbine designs.
- There is no need for stable towers because the gearbox, generator and other components are put on the floor.
- It can easily be installed as compared to other design of wind turbine.
- It can easily be transported from one place to another.
- The low speed of the blades make it low risk to birds and human.
- VAWT can withstand dire weather conditions such as being in the mountains etc.
- The preservation cost is low.

- This design does not require pointing in wind direction for efficiency so there is no Yaw drive and pitch mechanism are not necessary.

2.4.2.2 DISADVANTAGES OF VAWT

- Efficiency is considered really poor relative to HAWT. This is because only one blade of the wind works at a time.
- VAWT can create noise pollution.
- Guy-wire is needed to hold VAWT up
- VAWT need a beginning push to start; this beginning push that make the blades begin to spin on their own should be run by a tiny motor.
- They possess relative high vibration because the air flows near the ground create turbulent flow.
- Because of vibration, bearing wear is high which causes the cost to be expensive.

After explaining the types of turbines and how they work, their advantages and disadvantages here is a simplified picture showing how to transform wind power into electrical power

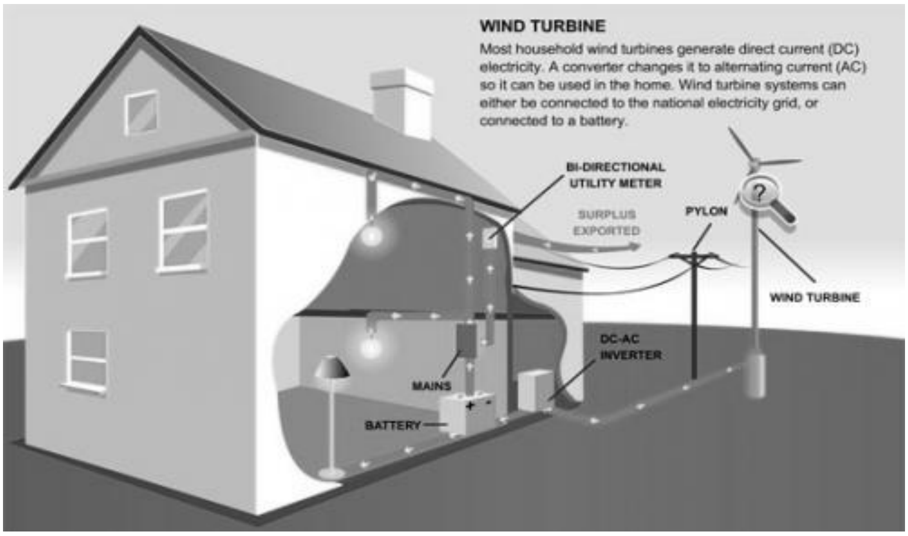


Figure 2.6: The conversion of wind energy into electricity

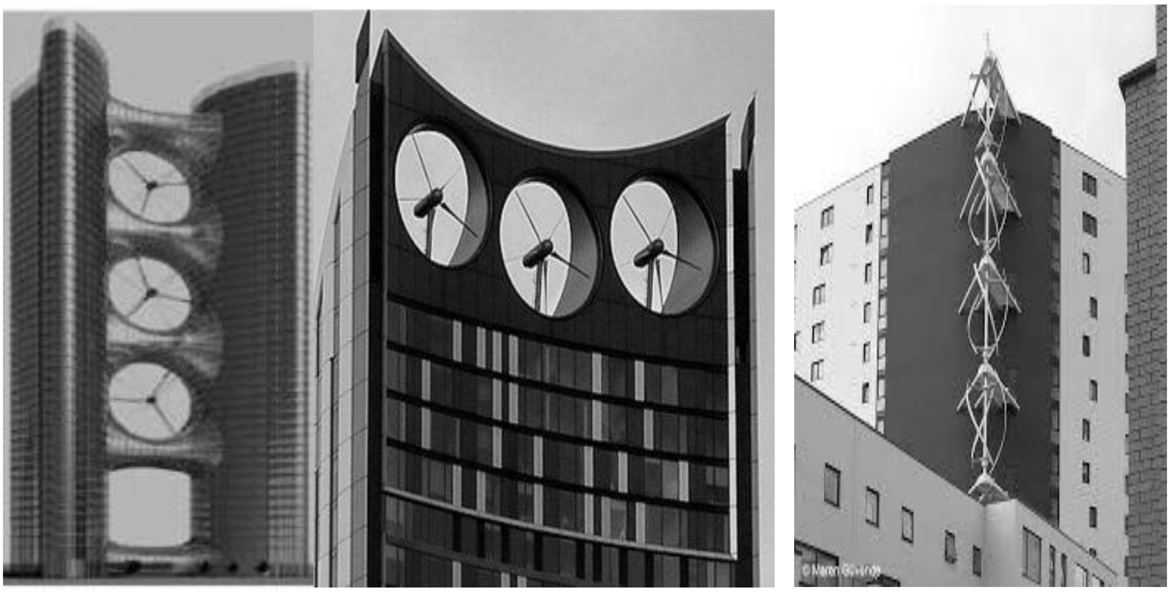


Figure 2.7: Different Types of wind Turbine installed on buildings

An analogy of horizontal and vertical wind converters can be summarized in the following table below:

Table 2.1: Comparison of VAWTS and HAWTS

	VAWTs	**HAWTs**
Tower sway	Tiny	Big
Tower machine	No	Yes
Whole formation	Easy	Difficult
General place	grounded	Not grounded
Height from ground	Tiny	Big
Blades operation area	Tiny	Big
Noisy machine	Low	Relatively
Wind direction	Independent	Dependent
Obstacles for birds	Low	High

CHAPTER 3
SAVONIUS WIND TURBINE

In this chapter, we talk about the history of Savonius and the materials used in it also made its work, as well as its advantages.

3.1 Background of Savonius wind turbine

The Savonius wind converter is a vertical axis wind turbine (VAWT) that was put forward by Savonius in the 1920s. The vertical axis wind turbines (VAWTs) consist of the cloud settings, for example Savonius rotor, and the lift type settings, for example Darrieus rotary. The easiest kind of vertical axis wind converters is the Savonius rotor, which depends on the difference in the force of clouds when the wind hits either a convex or a curved part of the semi-cylindrical blades. The Savonius rotors are great at automated runs and operate independently from the wind direction. However, their efficiency is relatively less than the efficiency of the VAWTs of the elevator type. Due to its easy patterns and cheap manufacturing costs, Savonius rotors are mainly used for pumping water and producing small-scale wind energy, and their high torque makes it suitable for starting other types of low-start wind turbines, such as rotary Darius and rotary mill (Li et al., 2004). Recently, some high-torque generators have been developed at a low rotational speed, ideal for tiny wind converters, meaning that Savonius circuits have potential to produce electrical power. (Morshed et al., 2013).

3.2 SAVONIOUS VERTICAL AXIS WIND

Savonius wind turbines are vertical axis wind turbines (VAWT) and are used for transforming the power of the wind into torque of a rotating shaft device. The converter is made up of a number of aero foils and is usually placed vertically on a rotating shaft device.

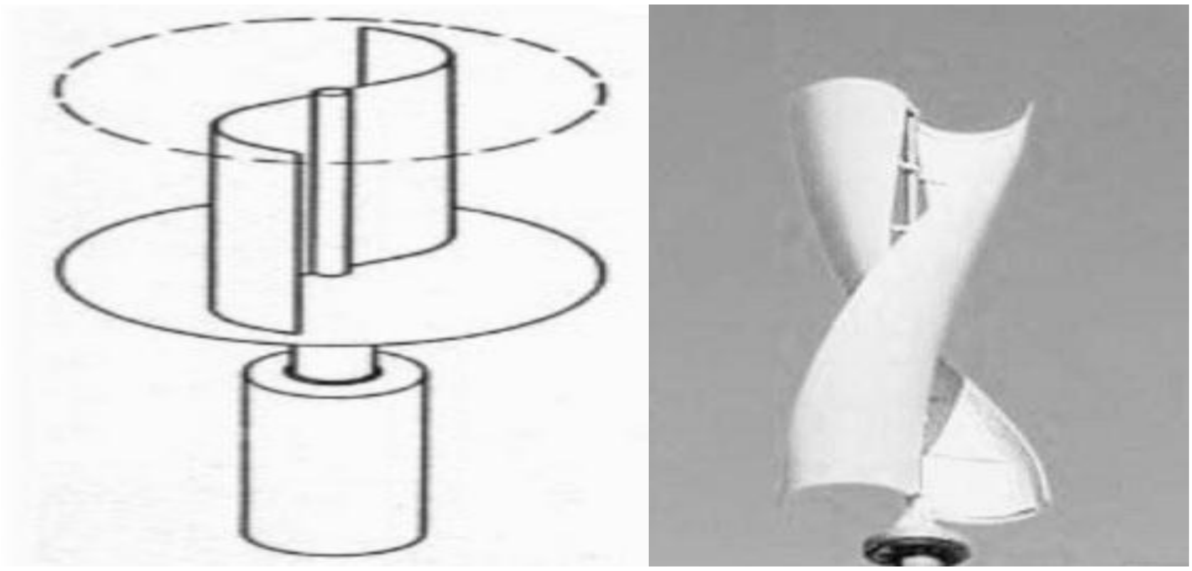


Figure 3.1: Savonius Vertical Axis Wind Turbine

3.2.1 Origin of Savonious Wind Turbine

Savonious wind turbine was invented in 1922 by a Finish inventor called Sigurd Johannes Savonius. Before this invention, the Europeans had carried out many experiments with curved blades for decades.

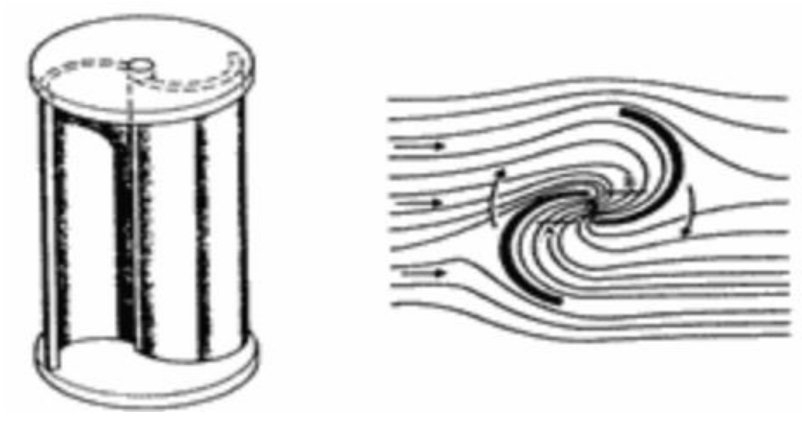


Figure 3.2: Origin of Savonious Wind Turbine

3.2.2 Operation

The savonius wind converter is a drag-type device and is one of the easiest to run of its kind. It is composed of two scoops which carry low drag when it is run in opposition to the wind than when it is in line with the wind. This is due to the curvature of the scoop which resembles an “S” shape in cross section, this differential drag makes the Savonius converter be in a spinning state. These converters generate a small amount of the winds energy when compared to closer machines which have a shape near this drag-type device.

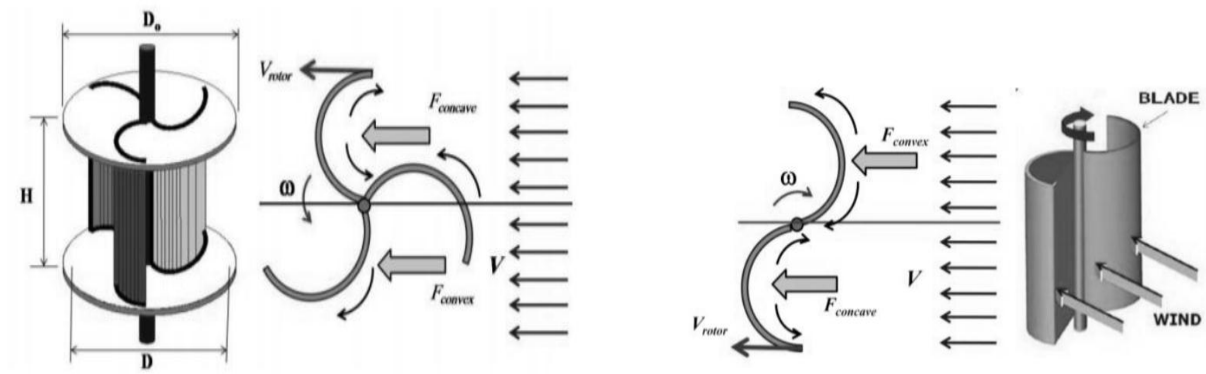


Figure 3.3: Working Principles of Savonius Turbine

Savonius converters are utilized as anemometers for measuring wind speed. Much larger designs are used for generating electric energy on deep-water buoys that require tiny amounts of power and title preservation. Savonius and other pumping device are very efficient in waterpumps and high torque, low upon. Notwithstanding, Savonius-style wind converters are different in a number of ways which will be explored below:

- It is a simple model that makes the manufacturing and preservation mechanisms easy and this makes them trustworthy machines.
- They have low operating velocity that doesn’t make them noisy when compared to other machines.
- The converters are able to be placed on tiny areas for example the roof of a building or in very tight and narrow areas

3.3 MATERIAL of Savonious Wind Turbine

(VAWT) Vertical Axis Wind Turbine rotors are growing in popularity due to its simple construction, economic and working relative to Horizontal Axis Wind Turbine (HAWT), HAWT is high in efficiency. For wind converters, the blades are the most essential device, their work rests on the substance, the kind of machine and designing of the blade. Substances that are utilized for Savonius Vertical Axis Wind Turbine (SVAWT) blades are Aluminum (7020 Alloy), Mild Steel (grade 55), Stainless Steel (A580) and Polycarbonate sheets. A technique Weighted Property Method (WPM) the technique to find out the most suitable material is by measuring the Polycarbonate sheet in optimization of the substance for blades production. And Polycarbonate sheet, among these optimized substance that are chosen for high production in converters, the chosen substances need to maintain low values in density for SVAWT, corrosion resistant, economic, good machinability and exceptional mechanical use(Sunny & Kumar et al., 2016).The installation of windmill through PVC utilizing blade substances. The PVC blades produce handy and excellent, fast, lightweight, low cost, versitile and really simple. Recently more growing interest by developers in utilizing big diamater PVC pipes as substances for blades. By cutting a PVC pipe lengthways and reshaping the leading and trailing edge with a file, and achieving almost a near perfect blade profile and the process is simple the Figure 3.4 shows the materials used in previous PVC.

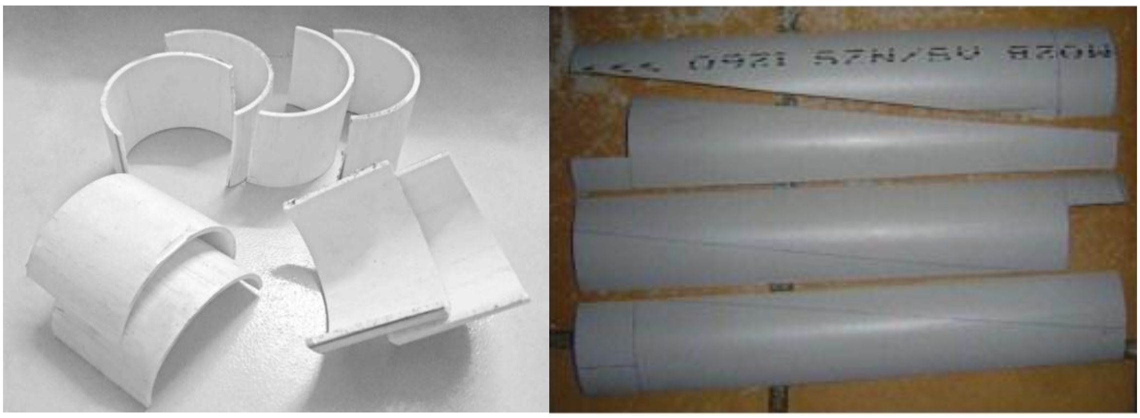


Figure 3.4: PVC Pipe Material

Wind velocity is measured at many locations by anemometer and only recently has the average velocity been considered of wind is 8 m/sec. this means we can reach an estimated energy of 300 W, In the beginning, the pipe needs to be quartered, next we draw a straight line and taking measurement on round surfaces. A big sheet of paper is narrowly placed around the pipe to reach a straight line round the pipe. Next we take one edge that is lined of the paper with this line to get straight lines going down the pipe. When the paper is placed in a circular manner with the pipe we can know exactly the circumference. Then paper can fold in half and half way mark it round the pipe. Then in half again and get quarters of the pipes. This mechanism which is utilized can give us a great way to draw suitable straight lines and then divide them to quarters.

The study proposes that PVC blade profile energy volume is given better when compared to increase in rotational speed of rotor. More studies are needed to support and verify these claims. (Patil ., 2011).From previous experiments, turbine output was extracted from 1 m / s to 7 m / s and the estimated power produced was 9 m / s. Power is generated from wind turbines if the wind speed is less than 3 m / s. The annual output of energy is 7838 kWh; the corresponding revenue is $ 846.51 (with contract price 20 years under the tariff at $ 10.10 / kWh). The market price for wind turbines ranges from $ 1000 to $ 3,000, depending on several factors such as repair and preservation. Assuming that all wind turbine costs are $ 3,000, the turbine will generate a net value of $ 13,967.4 per 20 years (Shah et al., 2018.) But it is better to use a small set of wind turbines at a lower cost that we will apply during this studying. Nonetheless, the Savonius converters generate a changeable torque and power output over a rotational interval, but it is poorly efficient when it is compared to primary converters such as HAWTs and Darrieus rotor. Savonius wind turbines is low are used when costs and reliability are more essential than being efficient for generating electrical power. (Mari et al., 2017)

CHAPTER 4
EXPERIMENTAL METHOD

This study is aimed to assess the availability wind potential using new configuration Savonius wind turbine for low wind speed at specific locations in Northern Cyprus. Therefore, this section is divided into two parts. In the first part, Weibull distributions: two-parameter Weibull probability (2W) and three-parameter Weibull distribution are used to analyze the wind speed potential based on averaged monthly wind speed data of five selected locations in Northern Cyprus. In the second part, new configuration Savonius rotors are designed experimentally. In addition, the mechanical and electrical powers are experimentally measured at various wind speeds. All the experiments are made using the rear exit of a wind tunnel in Mechanical Laboratory at Mechanical Engineering Department, Faculty of Engineering Near East University.

4.1 Statistical Analysis model

4.1.1 Data Measurement of Wind Speed in Cyprus

The wind speed data for this study were collected from the meteorological department during the period of 2010-2016. The data were taken as monthly values for seven years periods (January 2010 and December 2016). The data are measured at 10m and consisted of wind speed values and directions. The information and location of the selected regions are shown in Table 4.1and Figure 4.1

Table 4.1: Information from the selected regions

Station name	Coordinates		Measuring Height[m]	Period records	Year	Characteristics of the station
	Latitude [°N]	Longitude [°E]				
Dipkarpaz	35° 37' 36	34° 24' 31	10	2010-2016	7	coastal
Girne	35° 20’ 25	33° 19’ 08	10	2010-2016	7	coastal
Güzelyurt	35° 11’ 53	32° 59’ 38	10	2010-2016	7	coastal
Lefkoşa	35° 10’ 08	33° 21’ 33	10	2010-2016	7	Surrounded by building
Gazimağusa	35° 06’ 54	33° 56’ 33	10	2010-2016	7	coastal

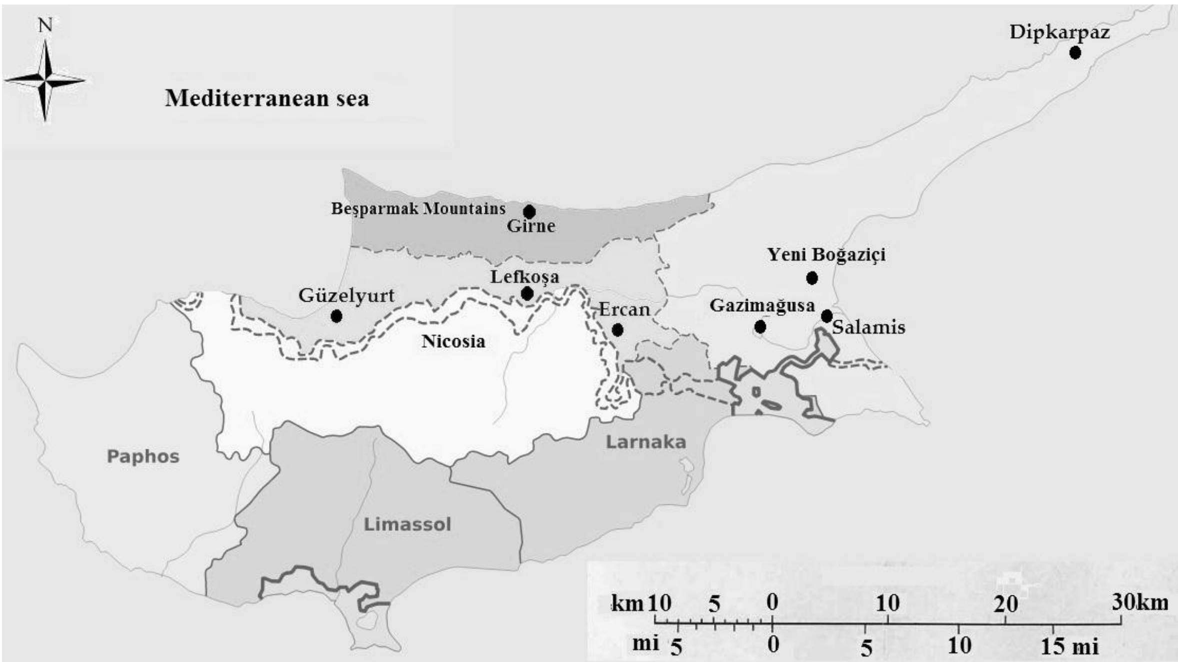


Figure 4.1: The geographic location of the study area

4.1.2 Probability Distribution of Wind Speed

Wind energy is a very local resource, and it should be studied in the exact location in which the wind conversion system will be placed. In this study, the selected locations could be considered as urban regions; therefore, the determination of wind speed at these regions is difficult due to the varying roughness, the drag exerted by surface-mounted obstacles on the flow and the presence of adjacent buildings (Kassem et al., 2019). Additionally, in order to assess the wind potential for a particular region in an urban environment based on data measured by meteorological stations, direct method (Weibull distribution function) and indirect method (atmospheric boundary layer wind tunnel testing and numerical simulation with Computational Fluid Dynamics) can be used. In general, the availability of wind energy and the performance of a conversion system for a specific location are estimated using wind speed distribution. The Weibull distribution is the most commonly used in analyzing the wind speed (v) characteristics at a pecific region. Maximum likelihood method (MLM) is widely used for estimating the Weibull parameters.

The probability density ($f(v)$) and cumulative distribution ($F(v)$) functions for two-parameter Weibull distribution... are expressed in Equation 4.1 and 4.2 (Bilir et al., 2015; Dabbaghiyan et al., 2016; Allouhi et al., 2017). In addition, the mean velocity of the two-parameter Weibull distribution ($\overline{v_{2W}}$) can be calculated using Equation 4.3.

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \tag{4.1}$$

$$F(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{4.2}$$

$$\overline{v_{2W}} = c\Gamma\left(1 + \frac{1}{k}\right) \tag{4.3}$$

Where *c* is the scale parameter in m/s and *k* is the shape factor of distribution.

Furthermore, the following equations gives the probability density and cumulative probability functions of three-parameter Weibull distribution (Wais., 2017 The mean velocity of three-parameter Weibull distribution ($\overline{v_{3W}}$) is estimated using Equation 4.6.

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v-\gamma}{c}\right)^{k-1} e^{-\left(\frac{v-\gamma}{c}\right)^{k}} \tag{4.4}$$

$$F(v) = 1 - exp\left[-\left(\frac{v-\gamma}{c}\right)^{k}\right] \tag{4.5}$$

$$\overline{v_{3W}} = c\Gamma\left(1 + \frac{1}{k}\right) + \gamma \tag{4.6}$$

Where k is the Weibull shape parameter, c is the scale parameter in m/s and γ is a location parameter.

4.1.3 Wind power density

The theoretically available kinetic energy that wind possesses at a certain location can be expressed as the mean available wind power (WPD). In other words, it is the maximum available wind power at each unit area. The mathematical expression for wind power density is given with the following relation (Olaofe & Folly., 2013):

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho\bar{v}^3 \tag{4.7}$$

Where $\overline{P}$ is the available power for wind per unit area in W/m^2 and ρ is the density of air in kg/m^3.

4.1.4 Wind speed at different hub height

Power law Model is widely used to calculate the wind speed (v) at various hub height of wind turbine (z) (Irwanto et al., 2014; Mostafaeipour., 2010). It is expressed as

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^{\alpha} \tag{4.8}$$

Where v_{10} is the wind speed at original height z_{10}, and α is the surface roughness coefficient Equation 4.9.

$$\alpha = \frac{0.37 - 0.088ln(v_{10})}{1 - 0.088ln(z_{10}/10)} \tag{4.9}$$

4.2 Experimental Model of Savonius Turbine and Apparatus

4.2.1 Rotor design and Fabrication

In general, Savonius turbine is a type of vertical axis wind turbine that consist two half cylinder blades. Several studied have investigated the effect of turbine geometric on the performance of Savonius rotor (Fujisawa & Gotoh 1994; Coton et al., 1996; Alexander & Holownia., 1978).). In the present work, two-, three- and four-bladed rotors have been studied using semicircular blades. Top view and isometric view of the new Savonius-style rotors are shown in Figure 4.2. The blades of rotors are manufactured from light plastic (PVC) tubes with different heights (300mm, 600mm, 900mm and 1200mm). The shaft of the rotor is made from stainless steel with 20 mm diameter and 1300 mm long. An attempt has been made to study a variety of rotor configurations with various aspects and overlap ratio. In this study, the overlap ratio is the ratio between the external overlap (L') and the blade diameter (D). The external overlap is the distance between the desk and rotor blade and L is the distance between the center of the shaft and rotor blade as shown in the Figure 4.2. The wind turbine models were built with various external overlap. It is known that the large external overlap (L') leads to increase the torque and reduce the angular speed of the shaft. In the present investigations, two desks were made from fiberglass with a thickness of 5 mm and placed on the top and bottom of the model. In the present investigation, two desks are placed on the top and bottom of the model. The distance between the two desks depends on the height of the rotor blades. Dimensions of design parameters are shown in Table 4.2.

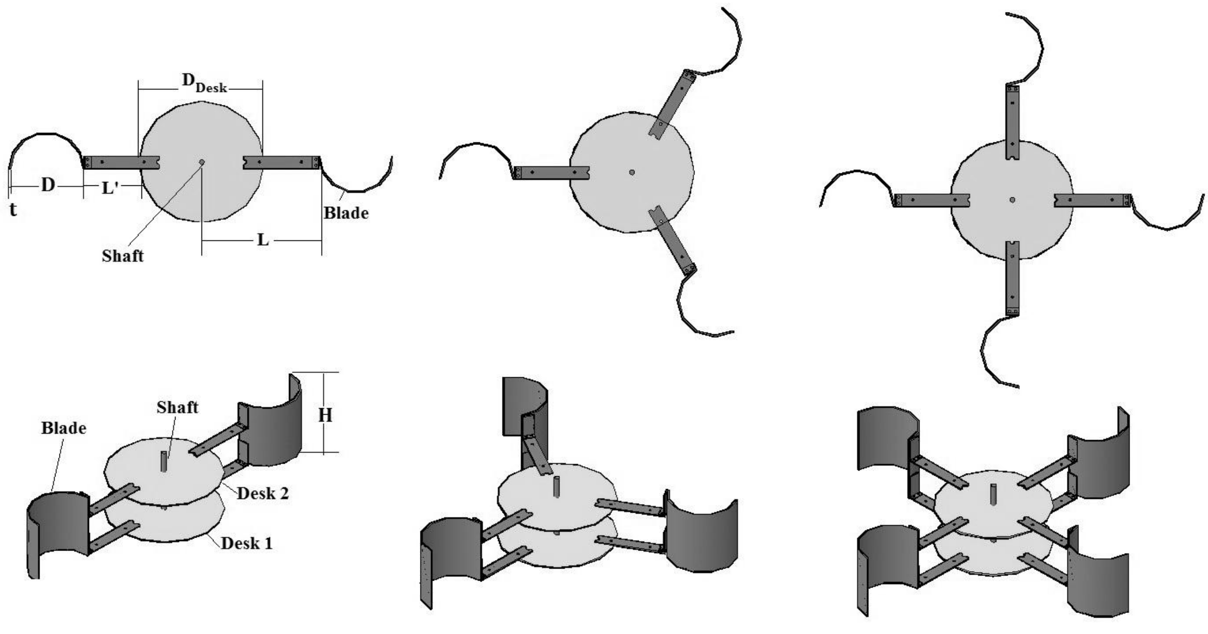


Figure 4.2: The schematic shapes of the new Savonius-style rotors

Table 4.2: Fixed and variable parameters of the design

Category	Design parameter	Value
	1. Blade	Semi-cylindrical
	2. Number of blades (N)	N = 2, 3and 4 blades
Physical features	3. Blade material	Light plastic (PVC)
	4. Desk material	Fiberglass
	5. Shaft material	Stainless steel
	6. Blade diameter (d)	d = 200mm
	7. Blade thickness (t)	t = 3 mm
Dimensional	8. Desk diameter (D)	D= 300 mm
	9. Blade height (H)	H = 300, 600, 900 and 1200
	10. External Overlap (L)	e = 0, 150, 300 and 400 mm
Operational	11. Rated wind speed (V)	V = 2, 3, 4, 6, 8, 10 and 12 m/s

4.2.2 Test Facility

In this work, a low-speed wind tunnel with an open test section facility with a cross sectional area of 1500mm× 1500mm was designed to evaluate the performance of the new configuration of Savonius turbine as shown in 4.3. The rotor was placed at distance of 200mm from the exit of the tunnel. The air velocity was varied between 0-15m/s and changed by the input voltage with the help of variac. Two Pitot tubes with an accuracy of ±0.1 m/s were used to measure the air velocity. RPM sensor was used to measure the rotational speed (RPM) of the rotor. In addition, the gearbox is used to increase the RPM delivered into the generator.

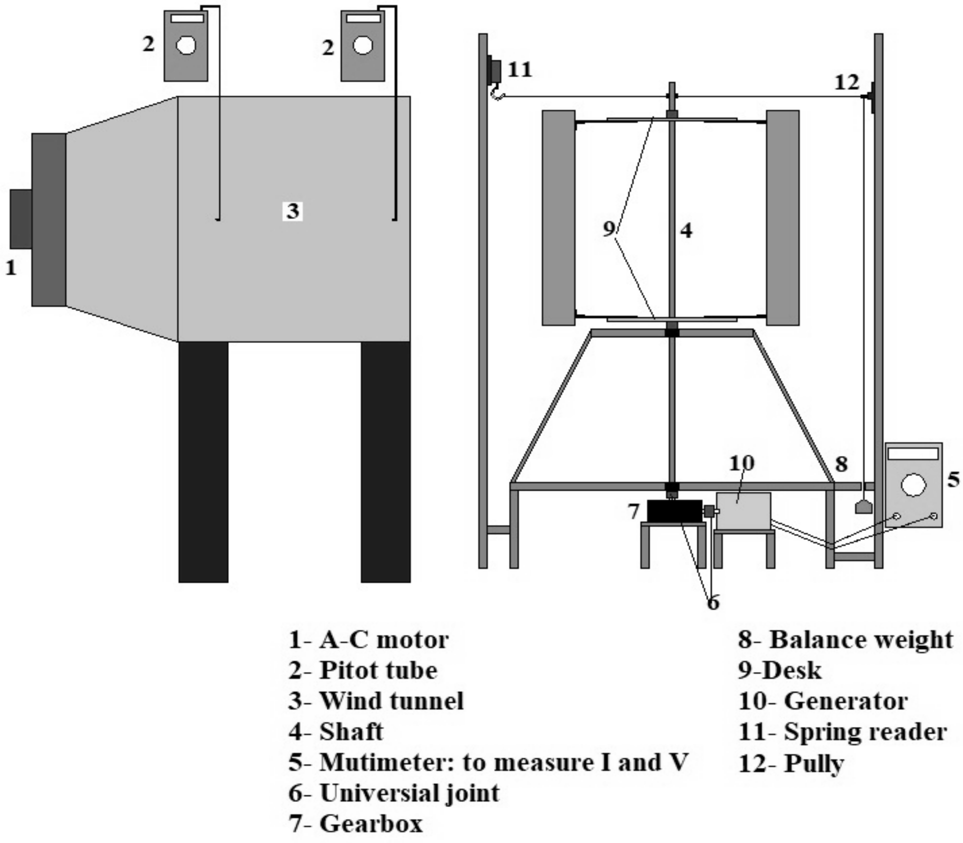


Figure 4.3: Schematic Diagram of the Experimental Setup

4.2.3 Experimental Setup

The experimental set-up used in this study, which was built according to Ref (Mahmoud et al. 2012; Kamoji et al., 2009). A schematic diagram of the experimental set-up that has been used in this study is shown in Figure 4.3. The experimental set-up consists of the wind tunnel, rotor, and measurement devices, namely pitot tube, RPM sensor, and a multimeter. The Savonius rotor is placed at its proper position using a structure housing fabricated from mild steel plates. Two bearings (UC 204, NTN make**)** bolted to the mild steel plates supporting the Savonius rotor. The seals are removed from the bearings and bearings are washed in petrol to remove the grease before mounting resulting in the reduction of friction. The usage of studs, nuts, and bolts in housing construction facilitates the replacement of various tested geometries of Savonius rotor and helps also in determining the proper position of rotor axis at the center line of the wind tunnel. Furthermore, to increase the amount of voltage produced by the DC machine which is to how fast the input shaft to the generator is rotating (in RPM), a gearbox was designed. Since the dimensions of the rotor were known and the wind speed could be measured, the amount of torque the rotor delivers under wind conditions could be calculated. The gear ratio was designed into the system on the unset 1:10. The rotors were attached to a gearbox, which was attached to generators. As a result, the amount of power generated by using gears was ten times greater than if the rotor were directly driving the generator shaft. The multimeter was used to measure voltage and current. Two Pitot tubes were used to measure the wind speed value and ensure that the wind speed is uniform. The measured velocity distribution at the rotor position is uniform within 3% in the central area of the wind tunnel. The turbine captures wind and moves due to the presence of drag forces, which cause to rotate the shaft around its fixed axis as shown in Figure 4.2. The support eliminates all kinds of vibration and ensures good stability of the setup during the experimental tests.

4.2.4 Experimental Methods

The mechanical power ($\boldsymbol{P_m}$) of the rotor is determined by measuring the torque on the rotating shaft and rotational speed (n) at different values of wind speed. From the measured values of mechanical torque and rotational speed, the mechanical power can be estimated at each wind speed as:

$$P_m = (m - s)g\left(r_{shaft} + r_{rope}\right)\frac{2\pi\ \mathrm{n}}{60} \qquad (4.10)$$

Where m represents the mass which is loaded in the pan in kg, s denotes the spring balance readings in kg and gravitational acceleration is denoted by g, r_{shaft} is the radius of the shaft and r_{rope} is the radius of the rope. As well, electrical power (P_e) generated by the wind turbine model is estimated by multiply the measurement current (I) and voltage (V), which are recorded by using multimeter device. The electrical power can be determined at each wind speed as:

$$P_e = IV \qquad (4.11)$$

4.3 Design a wind turbine

The power output of the wind turbine mainly depends on the wind speed value. The cut-in speed (v_{cut-in}), rated wind speed (v_{rated}) and cut-out speed ($v_{cut-out}$) are essential parameters to determine the performance of the wind turbine and all these parameters depend on the value of average wind speed (v_{avg}). These parameters can be determined as follow (Jain & Abhishek., 2016):

$$v_{cut-in} = 0.5v_{avg} \qquad (4.12)$$

$$v_{rated} = 1.5v_{avg} \qquad (4.13)$$

$$v_{cut-out} = 3v_{avg} \qquad (4.14)$$

The available wind power (Equation 4.15) exhibits the ideal power of a wind turbine, as in case of no aerodynamic or other losses during the energy conversion processes.

$$Available\ wind\ power = \frac{1}{2}\rho A v^3 \qquad (4.15)$$

Where A is the of swept in m^2 ($A = Height\ of\ blade \times rotor\ diameters$) and v is wind speed in m/s.

The ideal effectiveness of a wind turbine is called as Betz limit. According to the Betz limit (Awate et al., 2012), they are mostly only 59.3 % of the wind power can be converted into useful power. Some of the energy may lose in gearbox, bearings, generator, transmission and others (Jain & Abhishek., 2016). The highest power coefficient, Cp for Savonius rotor is 0.30. Hence, the Cp value used in this project is 0.30 and the power output in considering the power efficiency is calculated using Equation 4.16.

$$Available\ wind\ power = 0.15\rho A v^3 \qquad (4.16)$$

CHAPTER 5
RESULTS AND DISCUSSIONS

This section is organized as follows; the supposed of wind energy in Northern Cyprus has presented in term of monthly average wind speed and power density for different years (section 4.1). Section 4.2 is discussed the experimental results of Savonius wind rotors that can be used for distribution of generating electricity in small commercial and domestic use in Cyprus.

5.1 Availability wind potential

5.1.1 Wind speed characteristics

The descriptive of wind speed data during the investigation periods of each selected regions in terms of mean, standard deviation, minimum and maximum are presented in Table 5.1. It is found that the mean wind speed values are varied from 2.23m/s and 4.95m/s. The highest and lowest mean wind speed values are recorded in 2013 and 2012 at Gazimağusa and Güzelyurt, respectively. Additionally, Figure 5.1 shows the monthly mean wind speeds in the regions used in this study. It is observed that the maximum value of monthly wind speed of 7.22m/s was recorded in December 2013 in Gazimağusa while the minimum value as 1.10m/s was obtained in September 2016 in Güzelyurt. Moreover, it is noticed that the maximum and minimum annual wind speed are recorded in Gazimağusa and Güzelyurt with a value of 4.65m/s and 2.39m/s, respectively as shown in Figure 5.1.

Table 5.1: Wind speed description

Regions	Year	Mean	Standard deviation	Minimum	Maximum
Lefkoşa	2010	2.56	0.52	1.46	3.23
	2011	2.43	0.46	1.58	3.13
	2012	2.45	0.49	1.57	3.09
	2013	2.67	0.45	2.01	3.38
	2014	2.44	0.64	1.60	3.50
	2015	2.44	0.36	1.82	2.90
	2016	2.53	0.43	2.00	3.20
Girne	2010	2.42	0.45	1.57	3.26
	2011	2.39	0.27	2.05	2.85
	2012	2.33	0.39	1.80	3.17
	2013	2.60	0.40	2.05	3.38
	2014	2.48	0.42	2.00	3.20
	2015	2.57	0.35	1.95	3.05
	2016	2.53	0.35	2.00	3.10
Güzelyurt	2010	2.57	0.40	1.80	3.17
	2011	2.27	0.29	1.79	2.77
	2012	2.23	0.34	1.57	2.74
	2013	2.45	0.29	2.00	2.95
	2014	2.45	0.39	1.90	2.90
	2015	2.38	0.34	1.80	2.99
	2016	2.38	0.52	1.10	3.20
Dipkarpaz	2010	3.70	0.483	2.85	4.45
	2011	4.10	1.09	2.76	6.11
	2012	3.95	0.81	2.33	5.31
	2013	4.20	1.09	2.86	6.21
	2014	4.05	0.48	3.20	4.80
	2015	4.29	0.81	2.67	5.65
	2016	4.15	0.65	3.30	5.70
Gazimağusa	2010	4.43	0.46	3.96	5.50
	2011	4.74	0.53	4.11	5.67
	2012	4.62	0.77	3.89	6.54
	2013	4.95	0.88	3.72	7.22
	2014	4.50	0.36	4.00	5.10
	2015	4.71	0.65	3.77	5.50
	2016	4.61	0.62	3.80	6.00

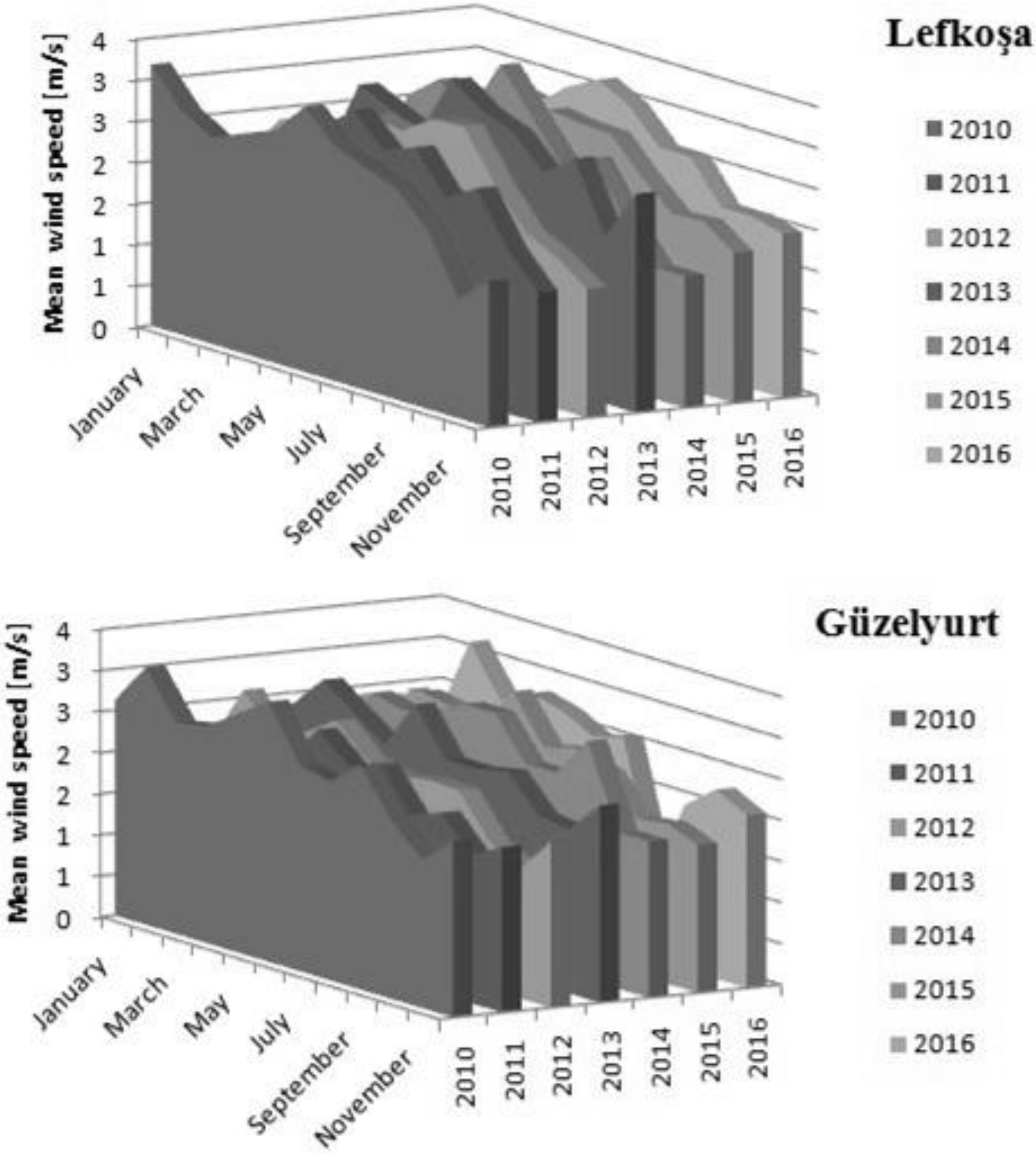
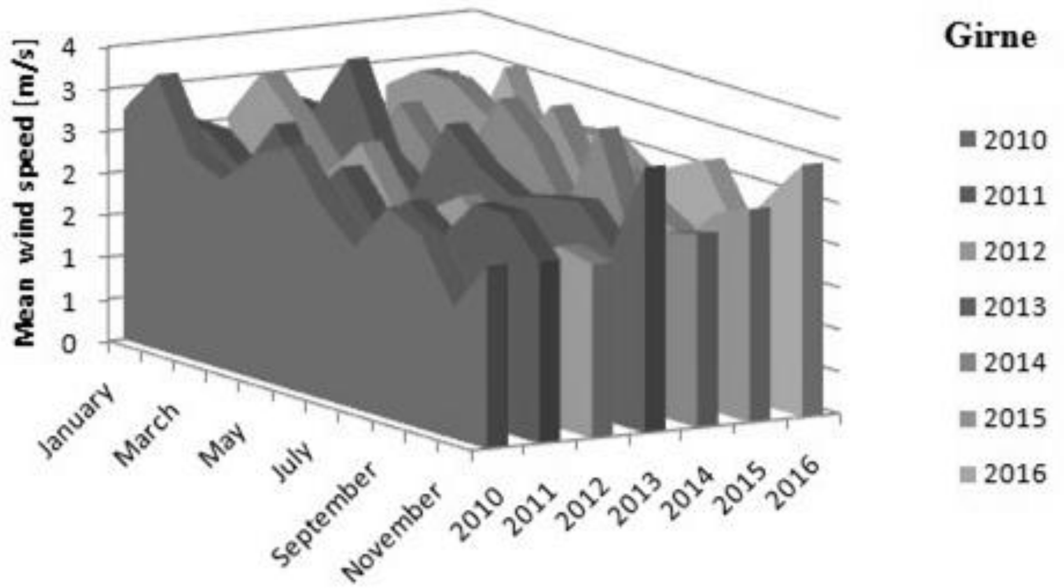


Figure 5.1: Monthly mean wind speed for all selected regions



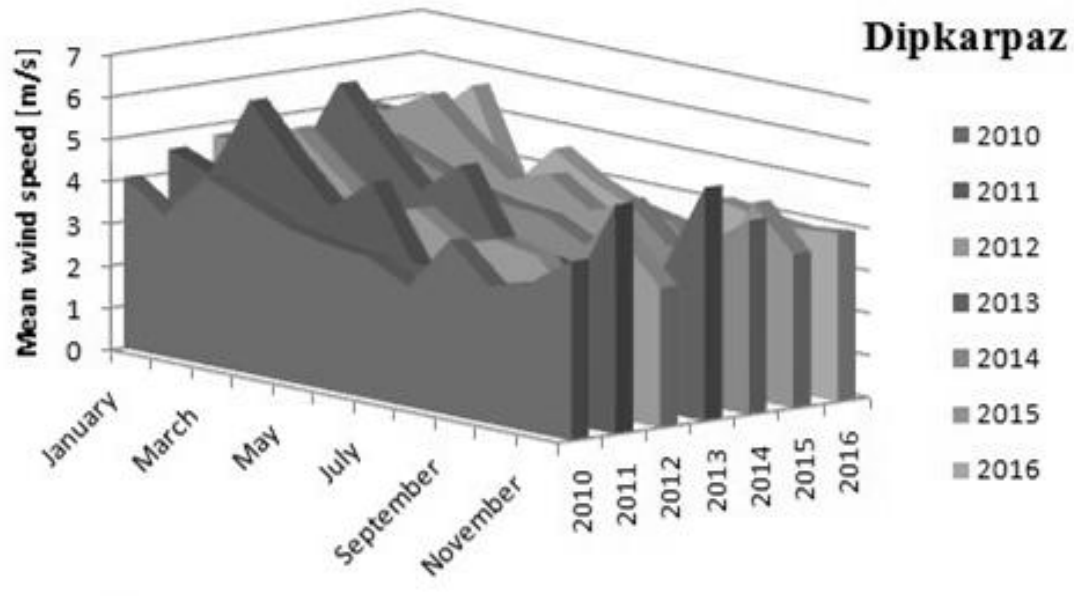
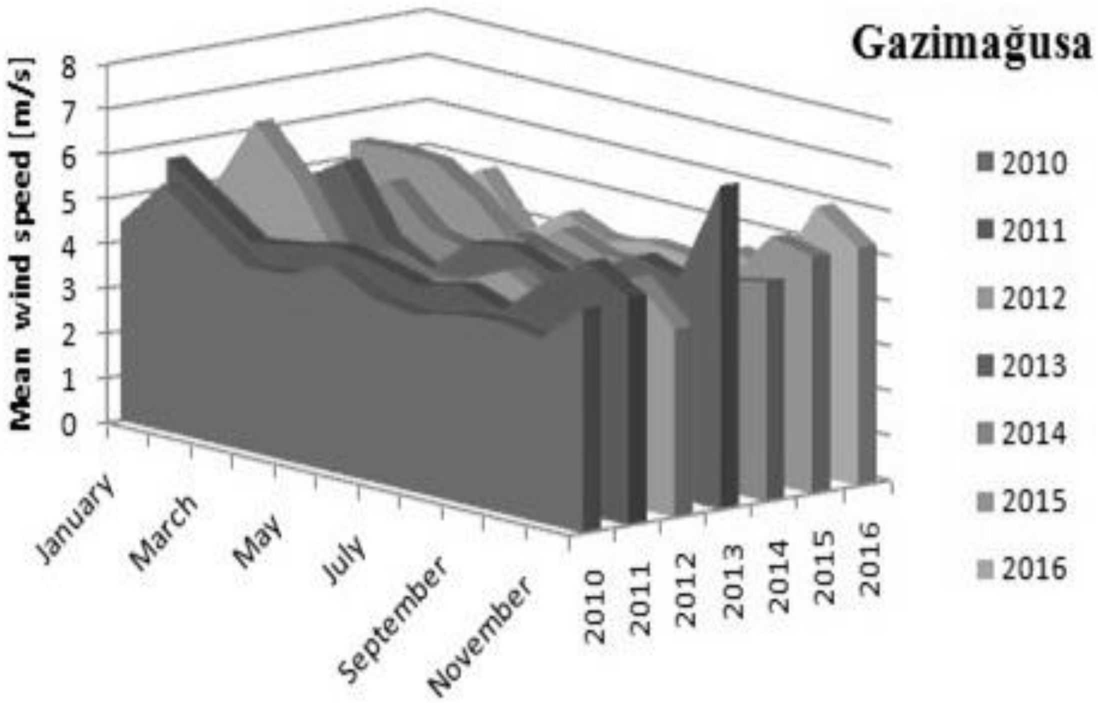


Figure 5.1: Continued



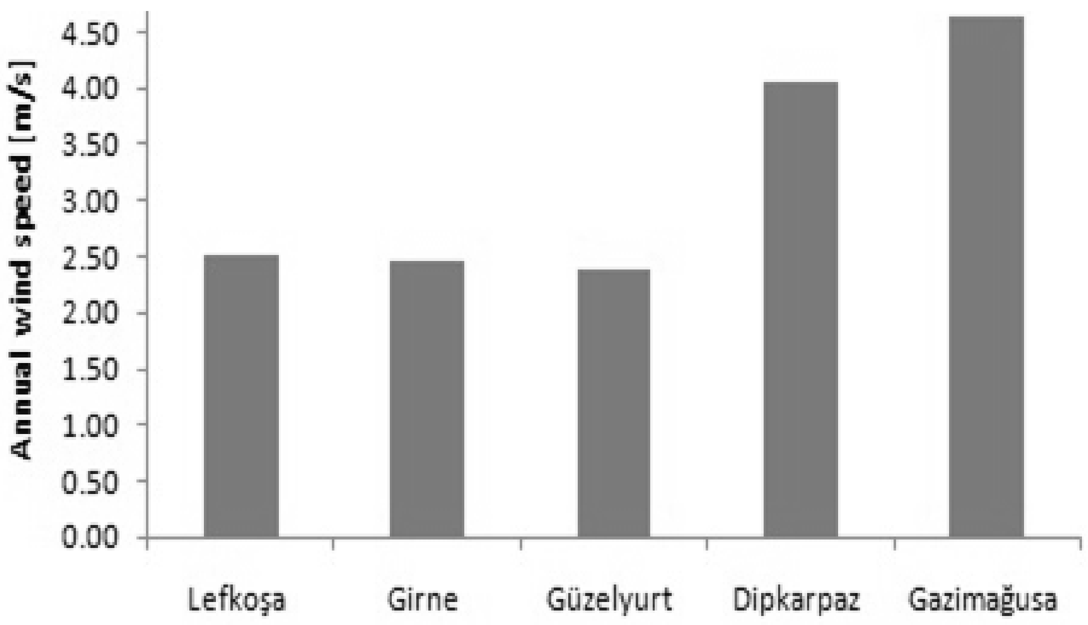


Figure 5.1: Continued

5.1.2 Wind directions

The direction of the wind was also recorded during the investigated years. Increasing wind frequency was used as an indicator of the main direction. Wind direction with the greatest frequency of the selected regions is tabulated in 5.2 Furthermore, the dominant annual direction of the wind for each region is summarized in Table 5.3 .As mentioned before, Famagusta has the maximum values of mean monthly wind speed; the dominant annual direction of the wind for this region was found to be Northeast (NE) and the highest wind frequencies of a value of 30.8% distribution occurred in October 2012. While the second direction from which the wind blows mostly was determined as the North (N) direction, with a value of 24.6% and recorded in March 2014. Similarly, it is observed that wind direction with the greatest frequency is NE for Lefkoşa with a value of 30.8% (October 2012). Additionally, it can be seen that wind direction with the greatest frequency is South (S) and Northwest (NW) for Girne and Güzelyurt, respectively. In addition, for Dipkarpaz, wind direction with the greatest frequency is N with a value of 31.9% (January 2015).

5.1.3 Hourly Variation of Wind Speed

Figure 5.2 shows the annual hourly variation of the mean wind speed for five regions. It shows that during the year, the average wind speed varies in the range of 1.25–6.25 m/s. In addition, it is seen that Gazimağusa has the maximum average wind speeds. From the graphs, it reveals that the coastal areas have a maximum, which occurs late in the afternoon and a minimum, which occurs in most cases between 5 and 6 a.m. In contrast, in the building areas (Lefkoşa), the maximum occurs in the afternoon at 2 p.m. and a minimum, which occurs in between 3 and 4 a.m.

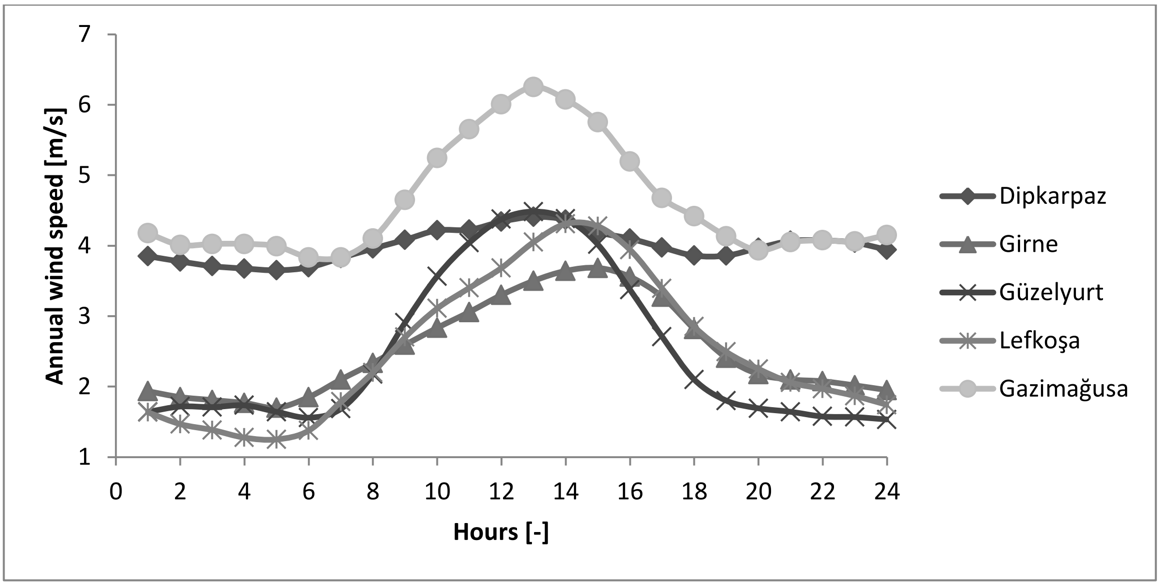


Figure 5.2: Annual hourly variation of mean wind speed for all regions

5.1.4 Weibull parameters and wind power densities

The distribution parameters values were calculated using the MLM method and tabulated in Table 5.4. In addition, mean and wind power are determined and listed in Table 5.4. Moreover, in order to select the best distribution that provides a good fit to actual wind speed data, the Kolmogorov-Smirnov test (KS) was used. The result of KS with the ranked distribution function is listed in Table 5.4. The lowest value of KS for distribution function is considered as the best distribution for analyzing the wind speed. It is found that 2W has the lowest KS compared to 3W and it is considered as the best distribution for examining the wind speed characteristics for Girne and Dipkarpaz. In addition, the results show that 3W describes the wind characterizations of Lefkoşa, Güzelyurt, and Gazimağusa better than the 2W distribution due to a minimum value of KS. The curve of wind speed distribution of the selected regions was obtained by using the probability density functions (PDF) is shown in Figure 5.3.

The wind energy potential classification according to the value of wind power density is presented in Table 5.5. Therefore, based on Table 5.4, it observed that all selected regions could be considered as class 1, which indicates poor wind power potential.

Table 5.2: Annual Weibull parameters, mean and wind power

Regions	Model	Parameter			Actual mean [m/s]	Available wind [W/m^2]	mean [m/s]	WPD [W/m^2]	KS	Rank
		K	c [m/s]	γ						
Lefkoşa	**2W**	6.153	2.619	-	2.50	9.587	2.260	7.073	0.1551	2
	3W	3.492	1.357	1.286			2.384	8.301	0.1424	1
Girne	**2W**	13.420	2.566	-	2.47	9.219	2.375	8.209	0.1589	1
	3W	1.824	0.398	2.118			2.432	8.810	0.2417	2
Güzelyurt	**2W**	10.700	2.505	-	2.39	8.345	2.280	7.260	0.2022	2
	3W	4.810	1.173	1.318			2.302	7.477	0.1646	1
Dipkarpaz	**2W**	6.699	4.333	-	4.06	40.938	3.774	32.925	0.1495	1
	3W	1.628	1.128	3.048			3.952	37.805	0.1529	2
Gazimağua	**2W**	12.020	4.850	-	4.65	61.582	4.454	54.129	0.2131	2
	3W	1.254	0.603	4.090			4.612	60.082	0.2044	1

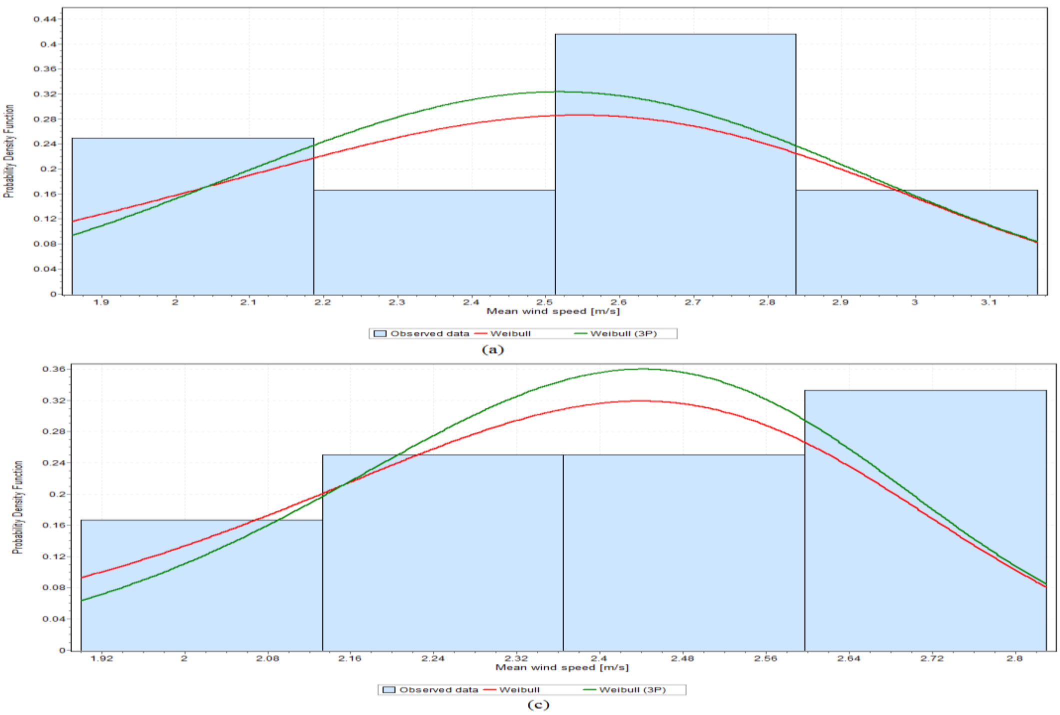
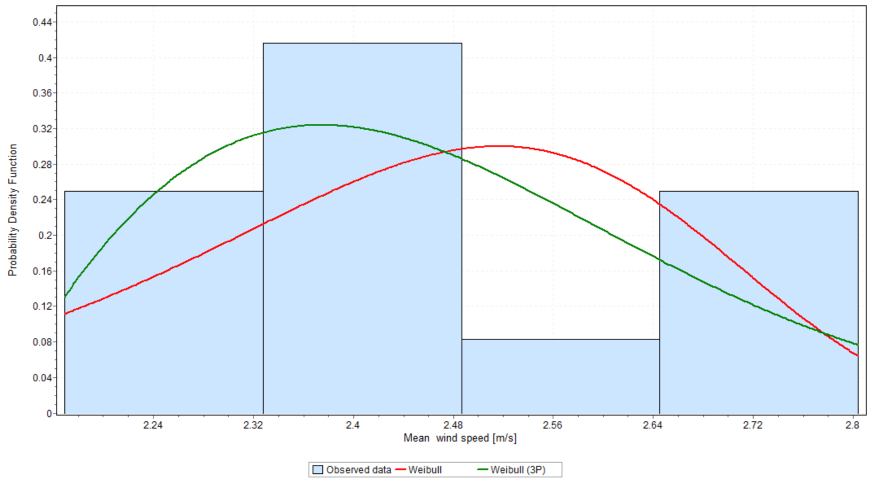
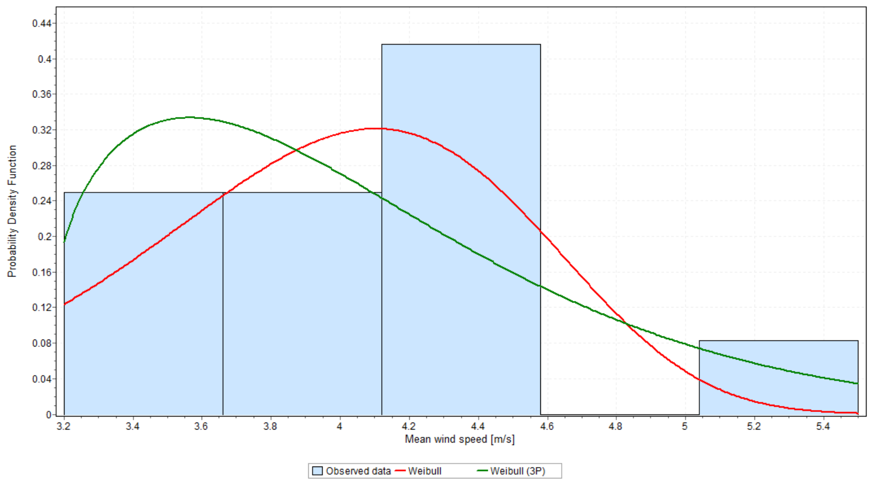


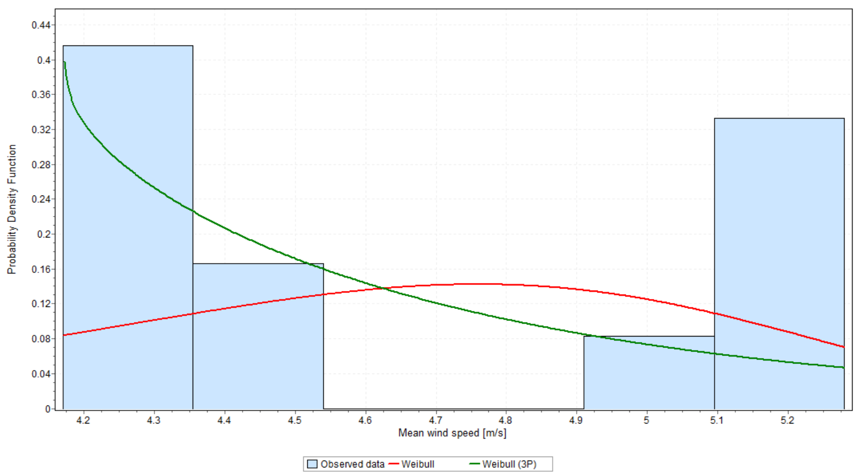
Figure 5.3: Weibull distribution of wind speed (2010-2016); (a) Lefkoşa, (b) (c)Girne,Güzelyurt, (d) Dipkarpaz, and (e) Gazimağusa



(b)



(d)



(e)

Figure 5.3: Continued

Table 5.3: The classification of wind power at the 10m height

Power class	Wind power density [W/m2]
1 (poor)	≤ 100
2 (marginal)	≤ 150
3 (moderate)	≤ 200
4 (good)	≤ 250
5 (excellent)	≤ 300
6 (excellent)	≤ 400
7 (excellent)	≤ 1000

5.2 Experimental results

5.2.1 Validation Study of Experimental Setup

This section shows the difference between the mechanical power values, which measured by the experimental setup of the current study and mechanical power results of Ref. (Mahmoud et al. 2013) by using the same dimensions of Savonius wind turbine (Figure 5.4), and wind speeds as shown in Table 5.6.The results show a similar trend in both the validation study mechanical power results of the current study and the mechanical power results of Ref. (Mahmoud et al., 2013). However, Table 5.6 shows that the mechanical power values of the present study for all velocities i.e. are agreeable with the experimental data of Ref. (Mahmoud et al. 2013). It is found that the absolute error values are ranged from 2.94% to 11.11%. This is maybe due to the thickness of the PVC used compared to PVC used in the experimental of Ref. (Mahmoud et al. 2013).

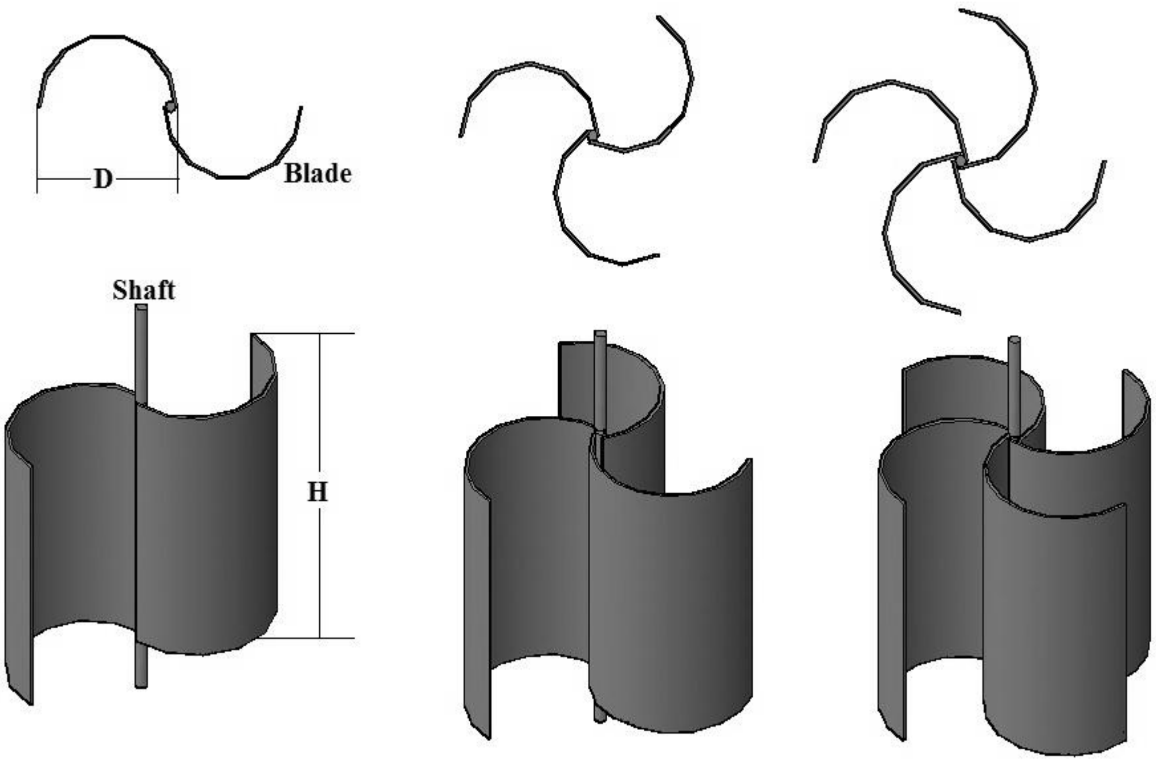


Figure 5.4: Savonius configuration

Table 5.4: Comparison of validation study mechanical power of current study with Mechanical power results

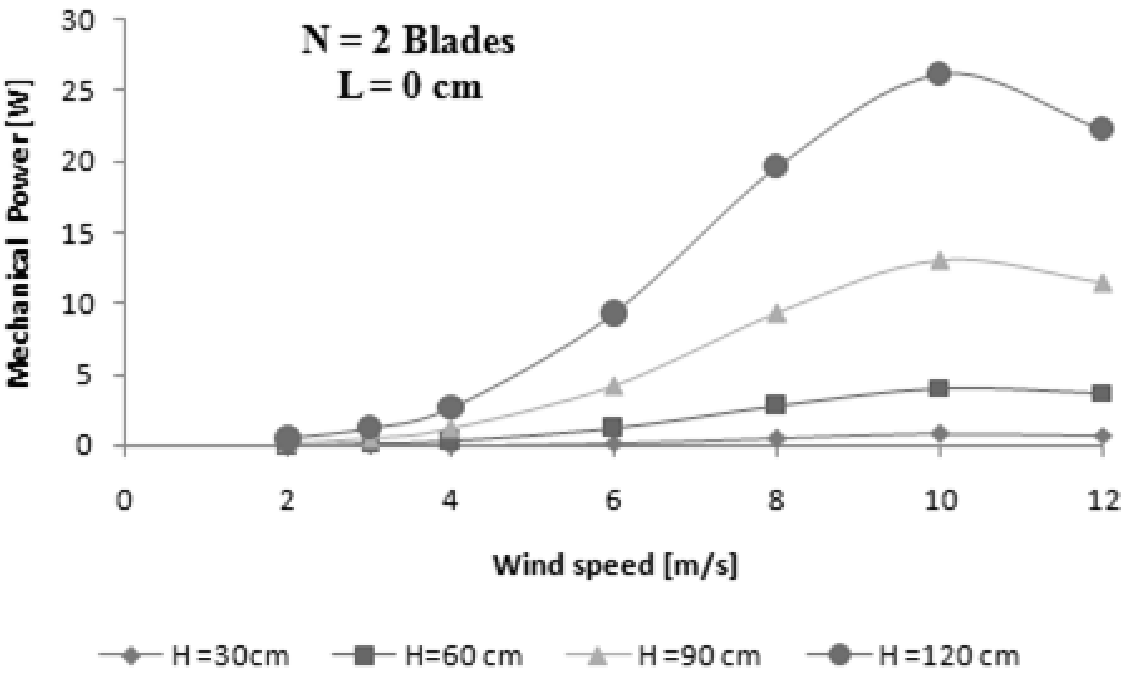
Blade diameter [mm]			Blade height [mm]			Absolute Error [%]		
100			500						
Wind speed [m/s]	Mechanical power results [Watt]								
	Mahmoud et al. 2013			**Current study**					
	N =2	**N =3**	**N =4**	**N =2**	**N =3**	**N =4**	**N =2**	**N = 3**	**N = 4**
6	0.23	0.25	0.18	0.25	0.27	0.20	8.69	8.00	11.11
8	0.52	0.50	0.48	0.48	0.52	0.52	7.69	4.00	4.00
10	2.70	2.20	1.70	3.10	2.50	1.75	7.40	4.54	2.94
12	3.40	3.85	2.50	4.00	3.67	2.65	2.94	4.67	6.00

5.2.2 Mechanical power of the rotors

Based on the experimental results, the 4-bladed wind turbine model has a higher torque than that of the 2- or 3-bladed wind turbine. In addition, the torque increases as the wind speed, blade height, and external overlap increases. From the results, it can be concluded that a four-bladed turbine should have about double or more weight to rotate when compared to a two and three blade turbine of the same size. In addition, the new Savonius-style with four blades has more drag force compared to other rotors at any position when the wind rotor is in rotational position. A wind turbine rotor with a higher number of blades will deliver higher torque for the shaft of the turbine. Generally, the torque of the 4-bladed rotor is higher than the torque obtained in both the 2- and 3-bladed rotors. This may be because the net drag force acting on the rotor in the 4- blade case is higher than those for the 2- and 3-blade cases. Figure 5.5 shows the effects of the number of blades, blade height and external overlap length on the mechanical power of the rotors. As seen in the figure, the 3-bladed wind turbine model has the highest Mechanical power for all cases. As the graphs there show, for all of the rotors, the mechanical power tends to vary polynomially with the wind speed. In the two-blade wind rotor, mechanical power will increase as wind speed increases, though it produces less power compared to the 3-blade and 4-blade rotors. In addition, it is observed that at wind speeds higher than 10 m/s, the 3- and 4-blade wind turbine have lower rotation rates and less power for wind speeds in the range of10 m/s to 12 m/s. That is to say, the three-blade wind rotor has better performance than the two- and four-blade wind rotor. At 10 m/s wind speed, power production from the three-blade wind turbine increases steadily and the rotation produced can exceed the rotation of the four-blade wind turbine. This shows that the wind turbine models reach an optimal rotational speed when the wind speed is around 10 m/s. The variations of mechanical power related to wind speed are shown in Figure 5.4. The three-blade wind turbine model achieves better stability for similar power values than the four-blade wind turbine. In general, It can be noticed from the results that a greater number of blades increase the weight to be turned by the turbine.

On the other hand, more blades provide a greater available surface area for the wind to push, so it would produce more turning power.

Having fewer blades could be beneficial because it will not be as heavy, and will be easier to turn than a greater number of blades, but it will also be inefficient because it produces less turning torque. Therefore, the 3-blade wind turbine models of 1200mm blade height have significant power at lower wind speed and more stable at a wind speed of 10 m/s. Additionally, it observed from the experimental results, the power and torque of the rotors are inversely proportional to rotational speed i.e. rotational speed of the rotor decreases as the overlap increases and torque of the model increases as the overlap decreases. The 3-blades wind rotor has better performance than 2- and 4-blades wind rotor for same geometries. At wind speed, 6 m /s to 10 m /s 3- blades wind, turbine model shows power increase steadily and the rotation produced can exceed the rotation of 4-blades wind turbine. Three blades wind turbine model gives power more stable than that 4-blades wind turbine. In addition, as observed during testing, when L is higher than 400mm, the rotors started shaking. This shows that at high wind speeds (above 4m/s); hence, the rotor becomes unstable. Not only this may reduce the performance of the turbine, but it may also even break down. Similarly, in the 4-blade turbine blade, at wind speeds higher than 10m/s the blades started shaking and became unstable, which indicate that the performance of the rotors will be reduced and may also even break down.



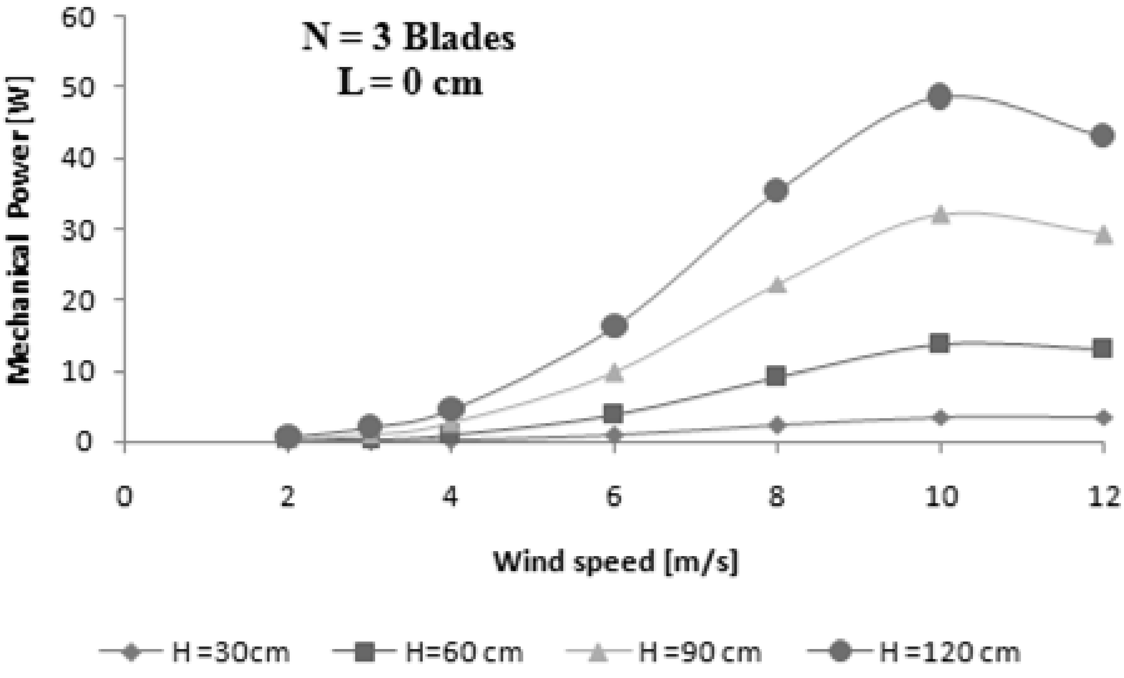
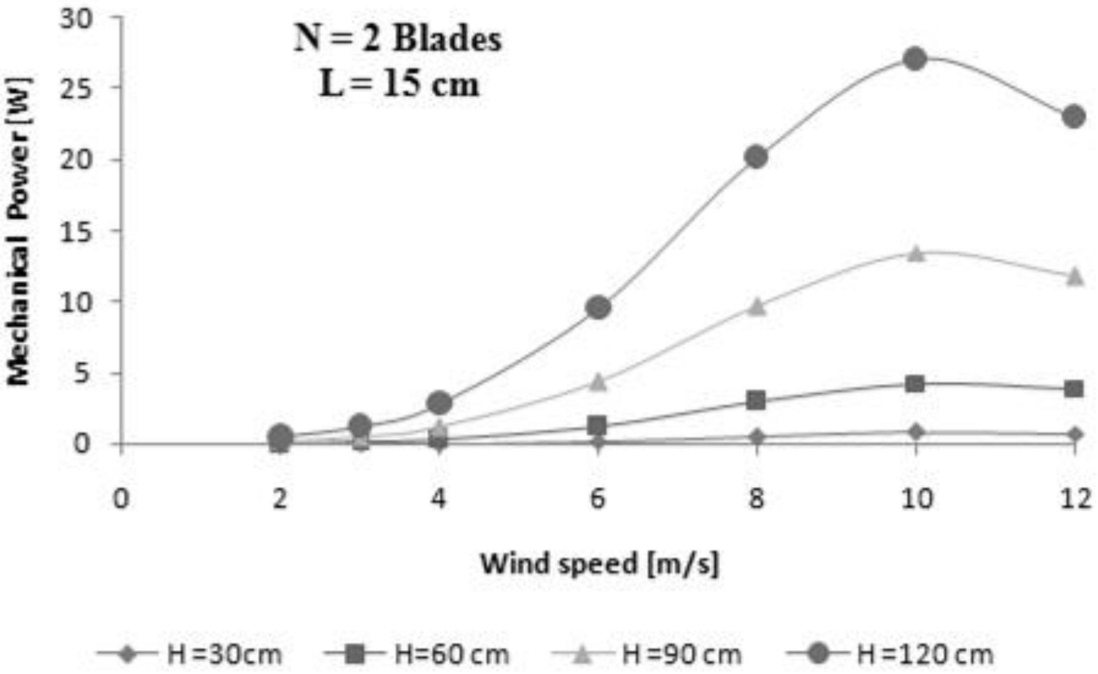


Figure 5.5: Mechanical Power versus Wind Speed for Different Blade Height, Blade Numbers and External Overlap



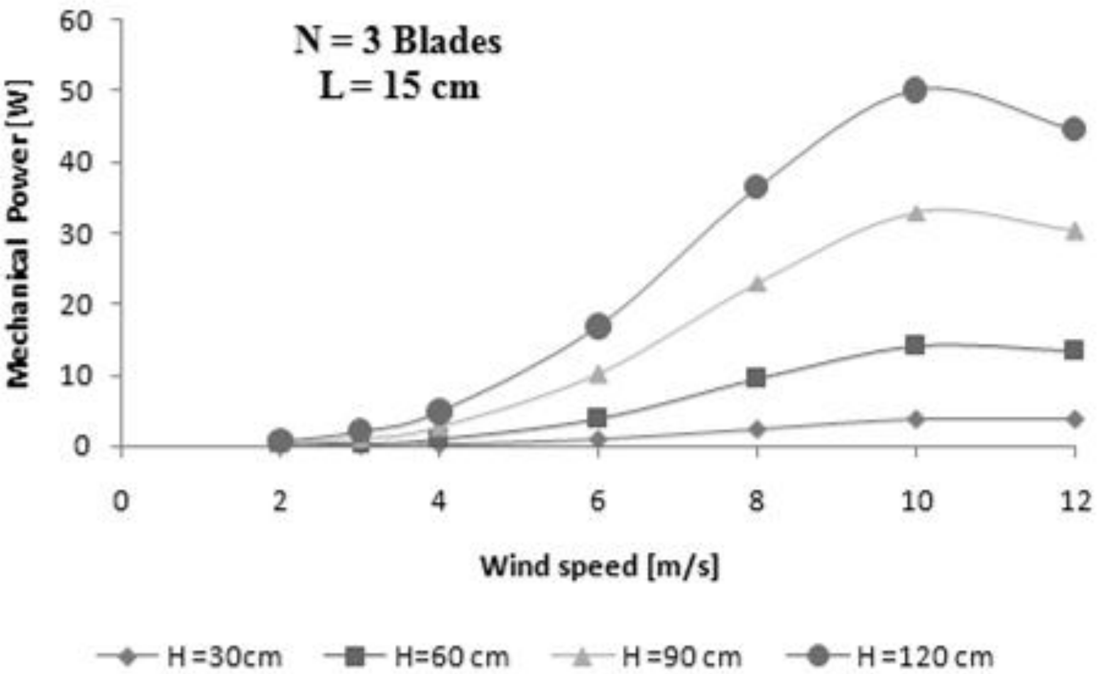
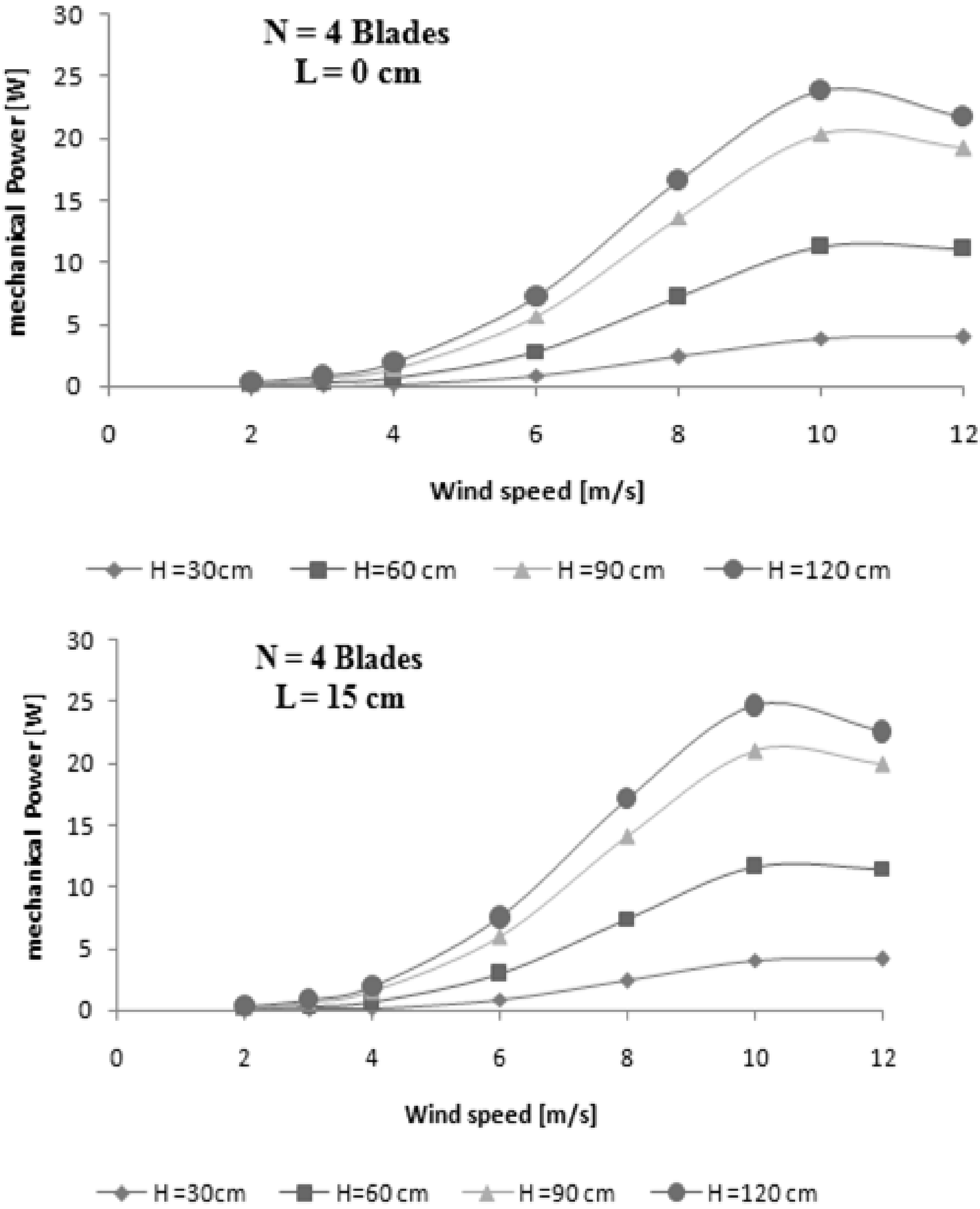


Figure 5.5: Continued



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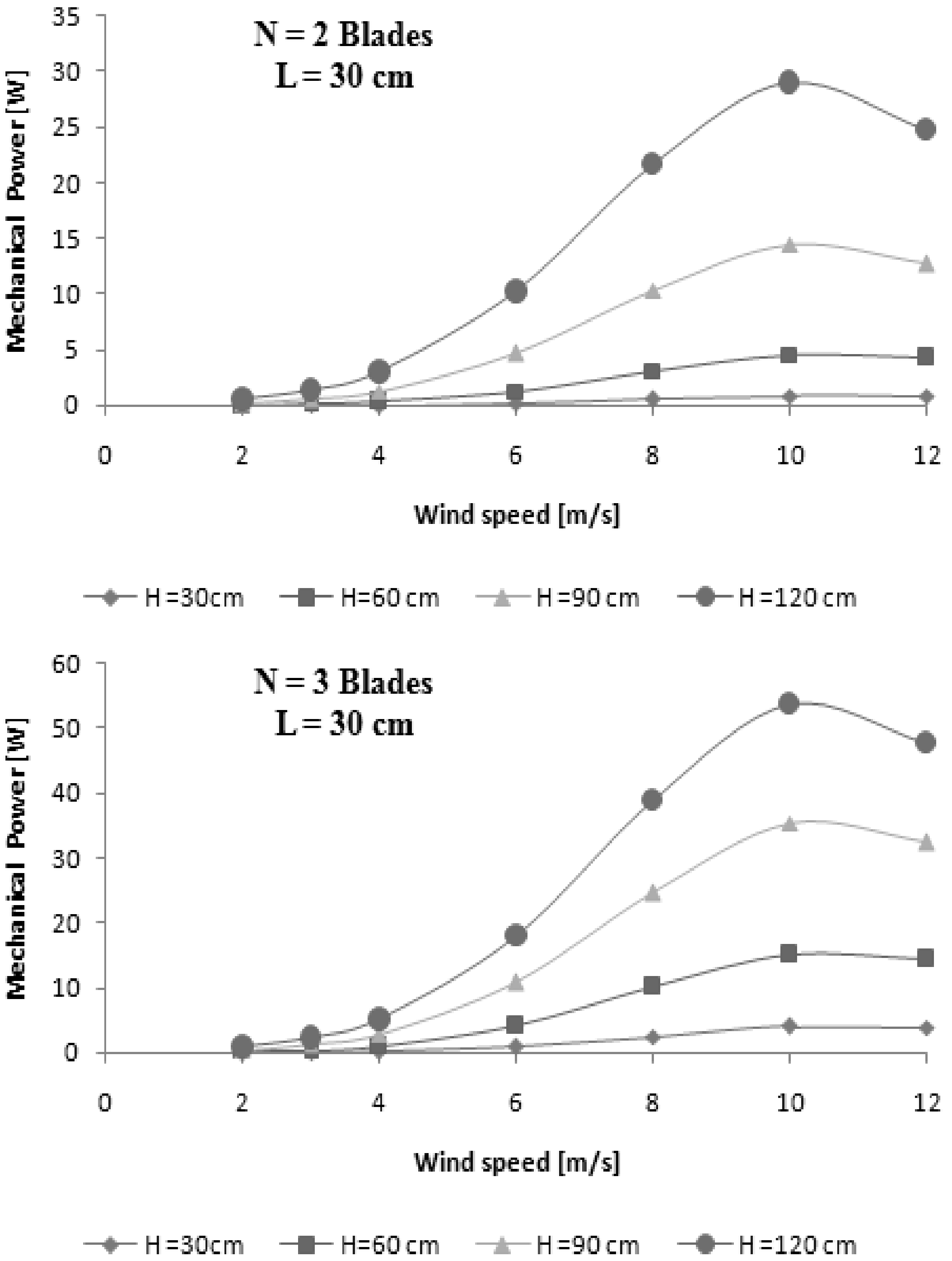

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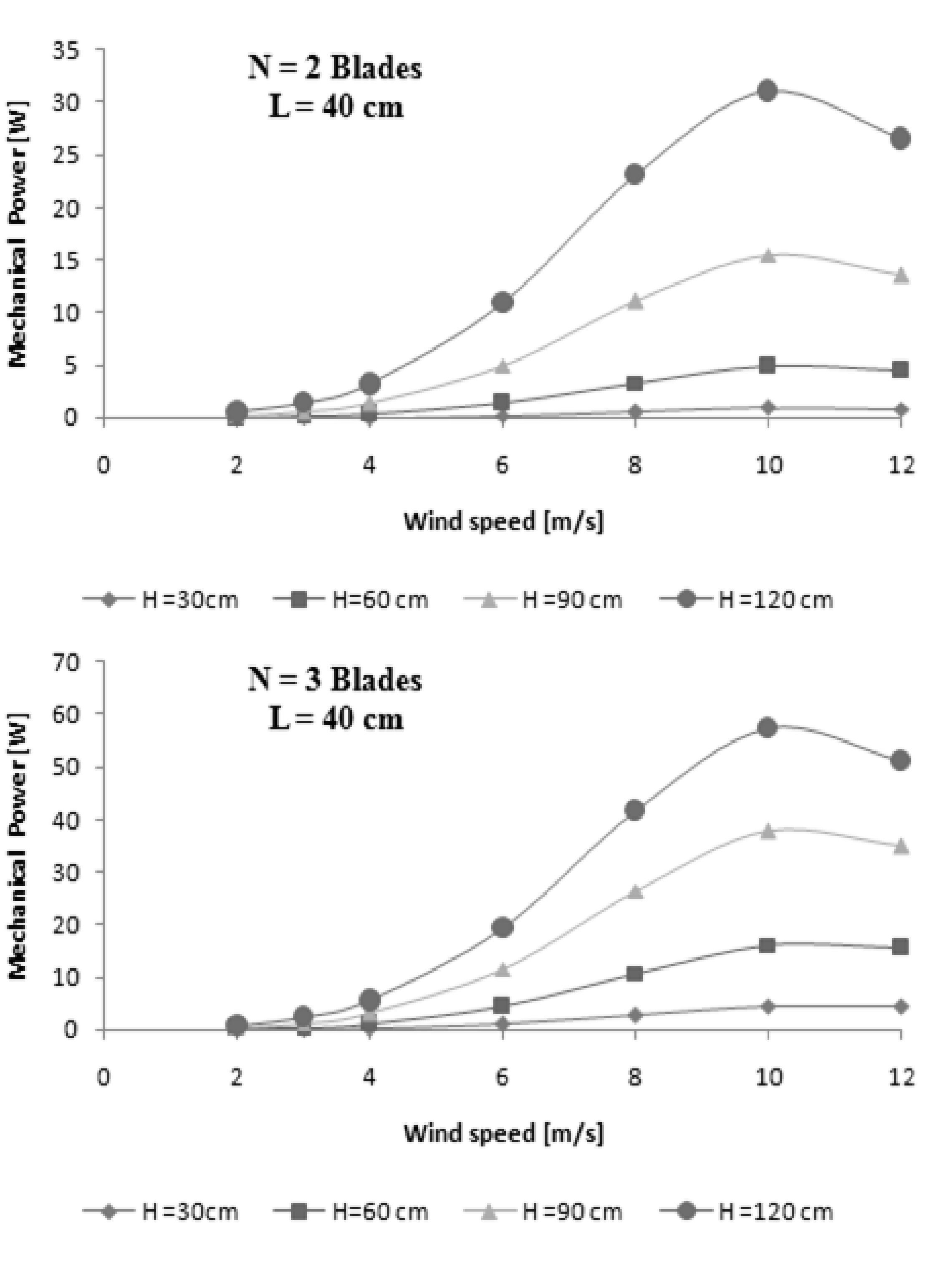

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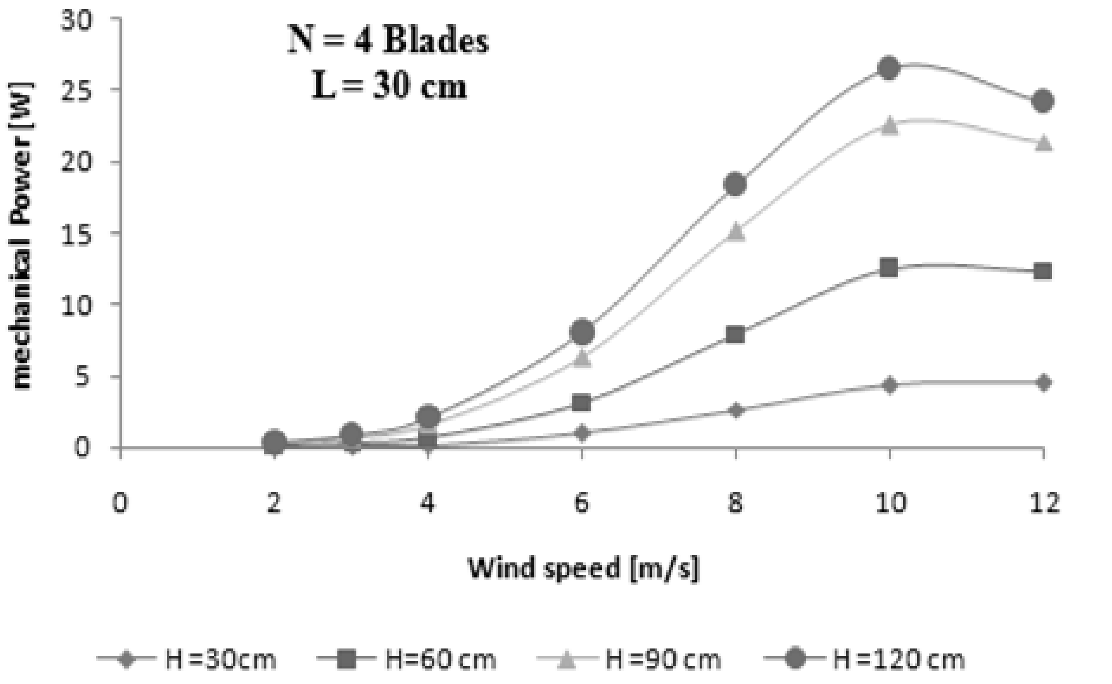


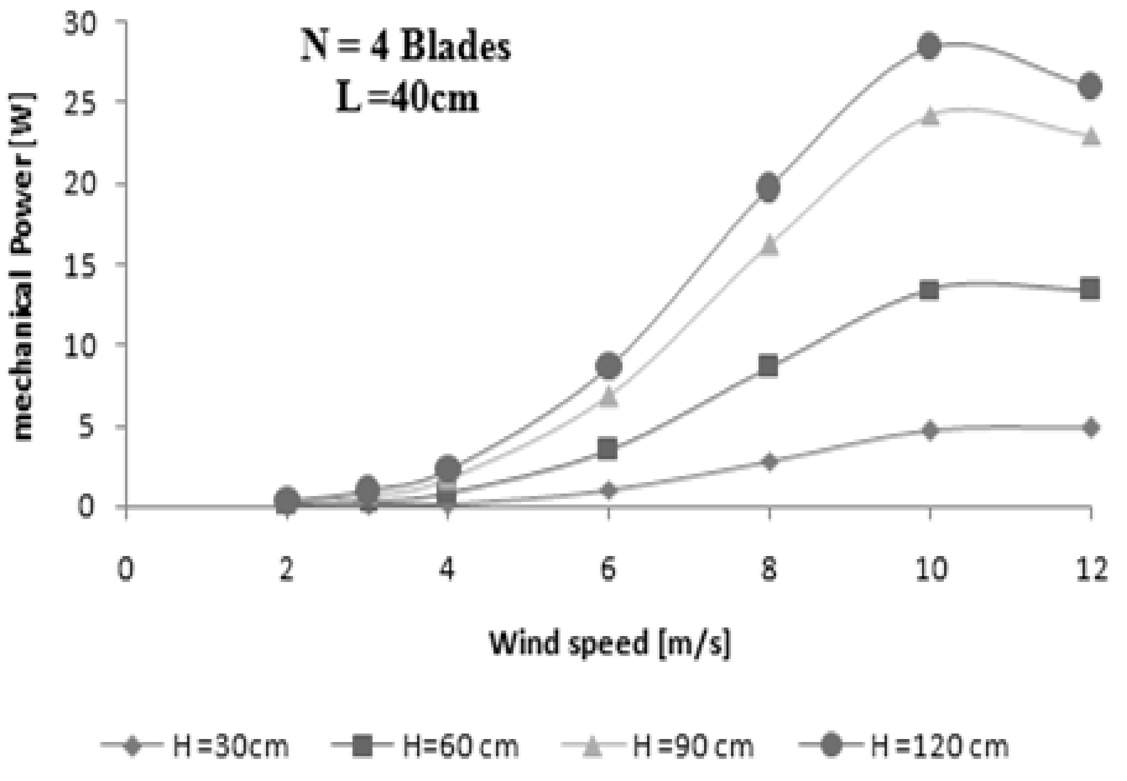


Figure 5.5: Continued

5.2.3 Electrical power of the rotors

In this current study, wind power generator with a capacity of 500W is used in this study. Figure5.6 illustrates the variation in electrical power with wind speed for the investigated rotors. The power for the 3- bladed rotors is produced the highest electrical power compared to 2- and 4-bladed rotors. This may be because the mechanical power on the rotor in the three- blade cases is higher than that in the 2- and 4- blade cases. Moreover, when the number of blades is increased to four, the air, which strikes on one blade gets, reflected back on the following blade so that the following blade rotates in the negative direction as compared to the preceding blade. Hence, with an increase in the number of blades, the rotor performance decreases. It can be concluded from the experimental data that a three-bladed system has better overall performance than the other models.

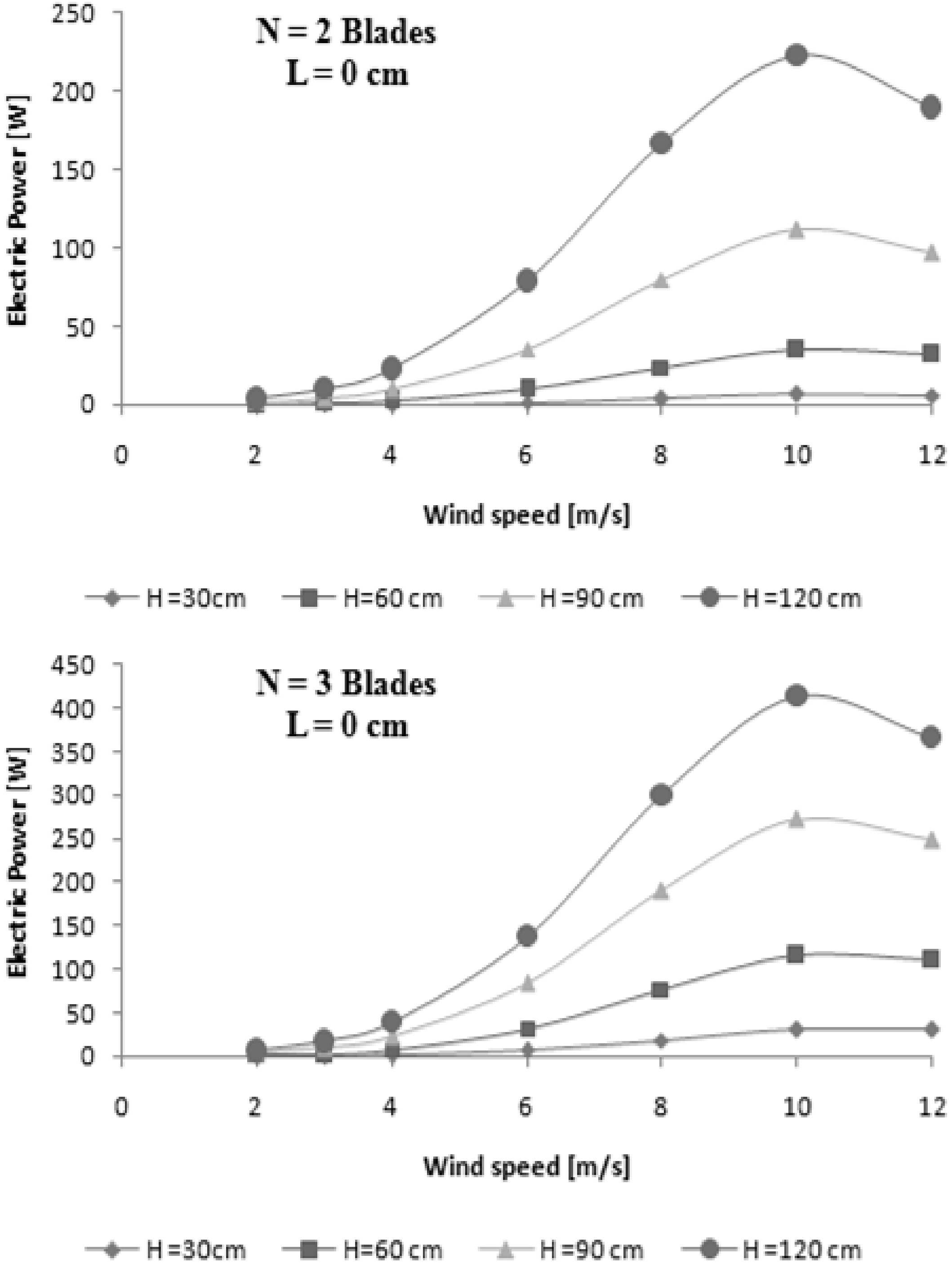
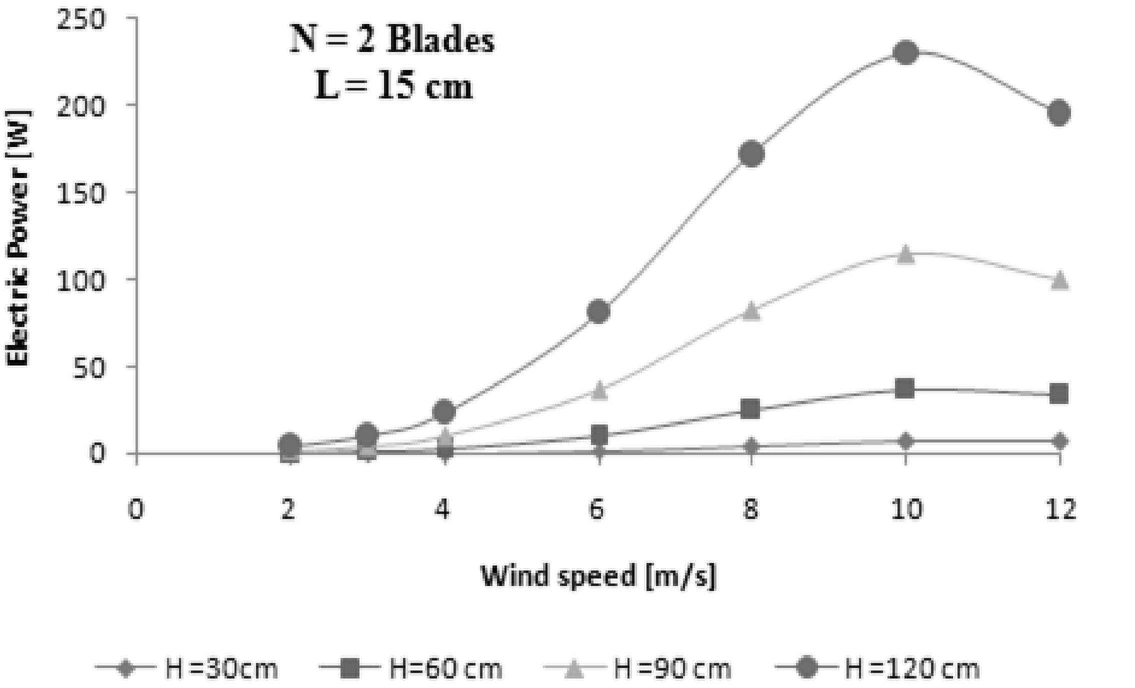


Figure 5.6: Electrical Power Versus Wind Speed For Different Blade Height, Blade Numbers and External Overlap



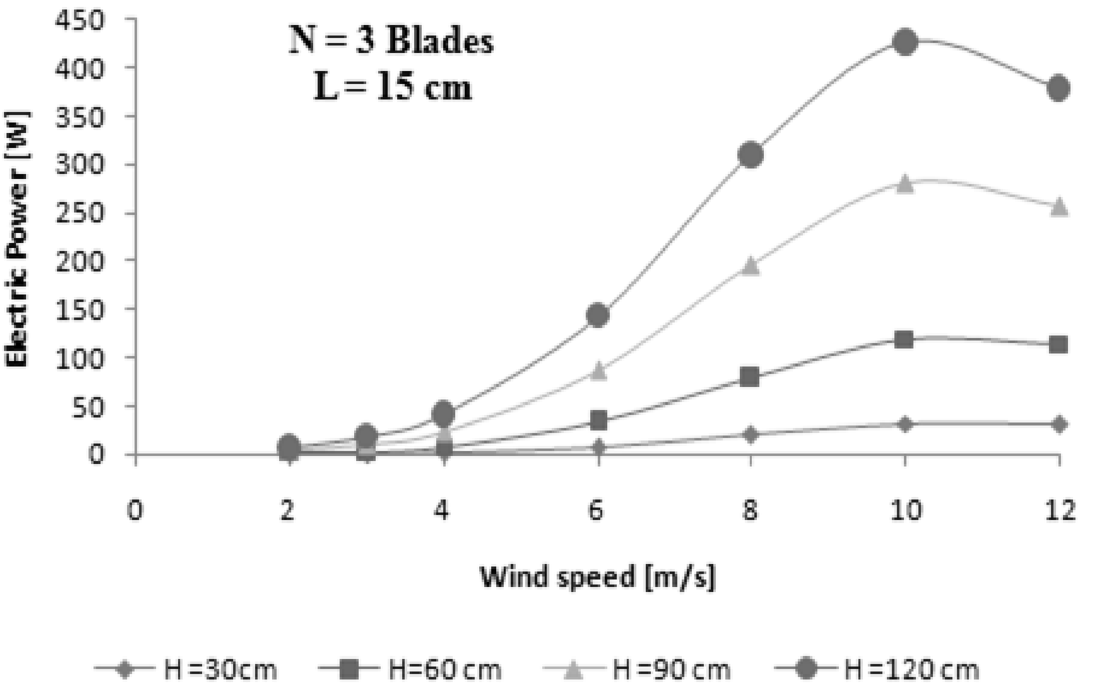
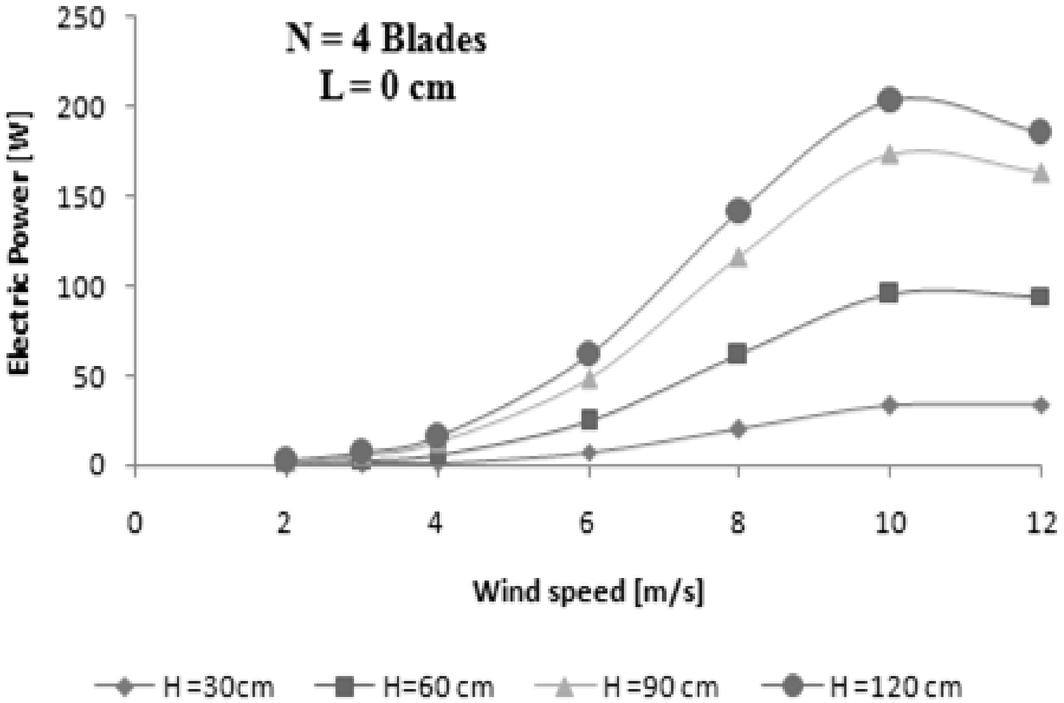
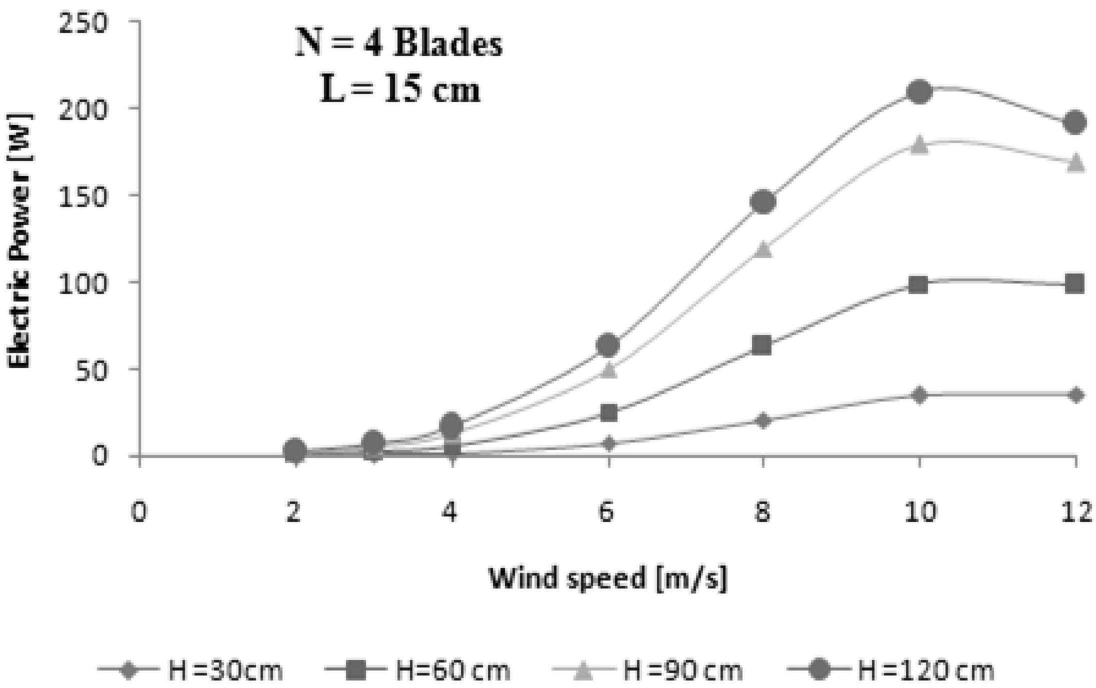


Figure 5.6: Continued





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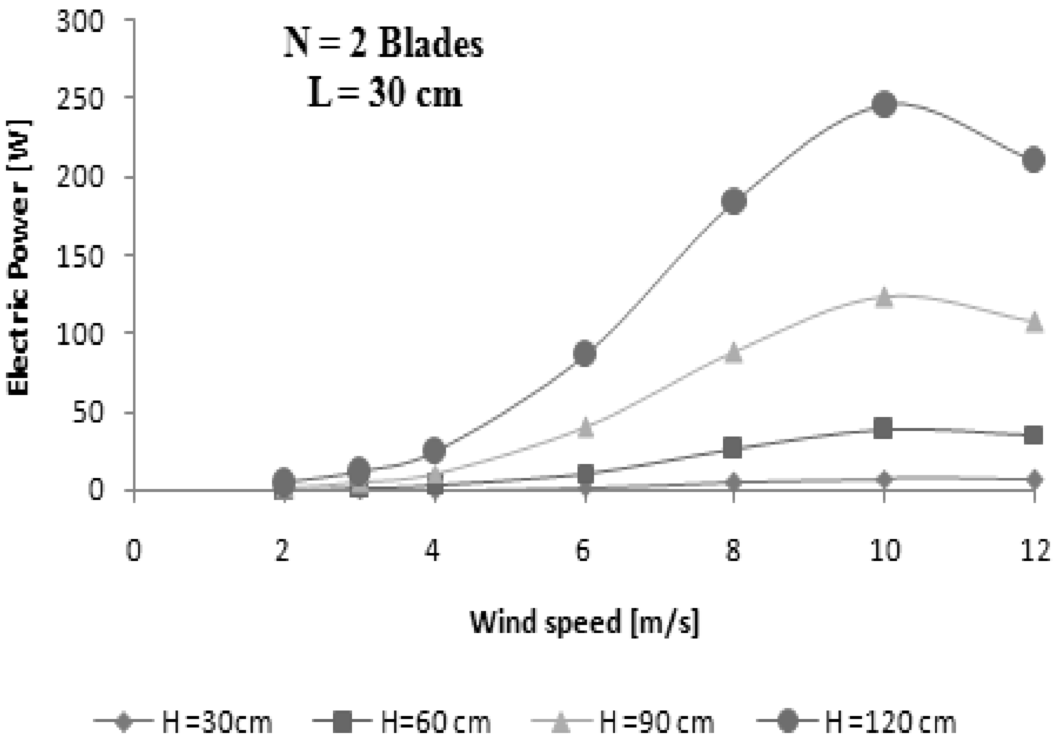

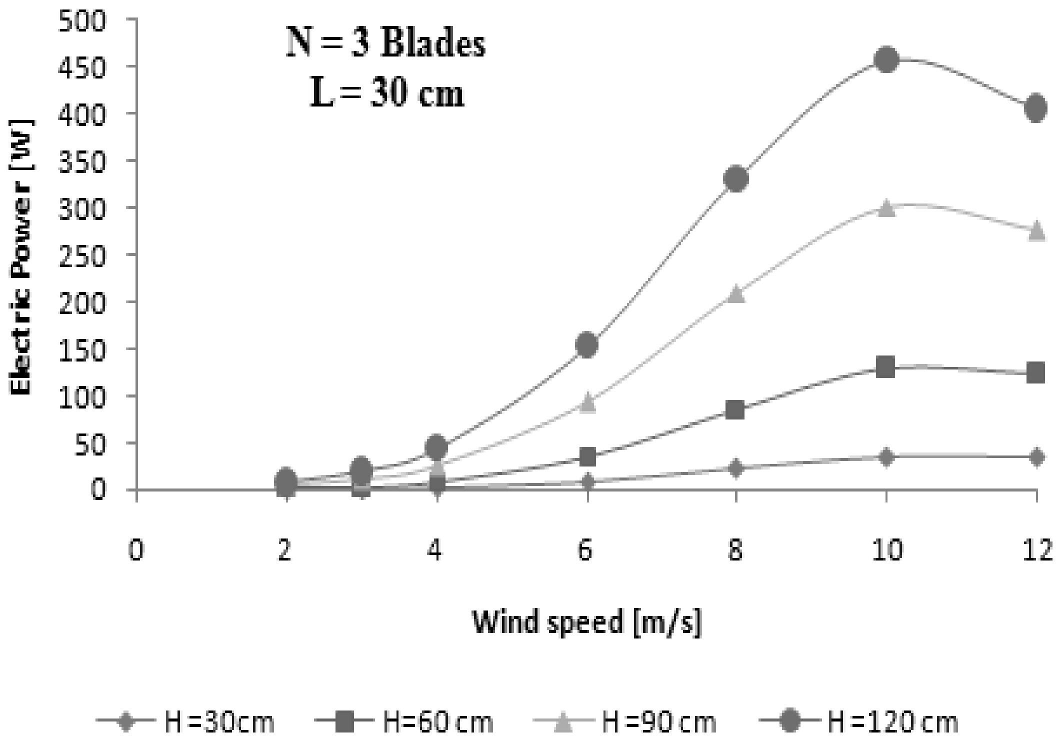

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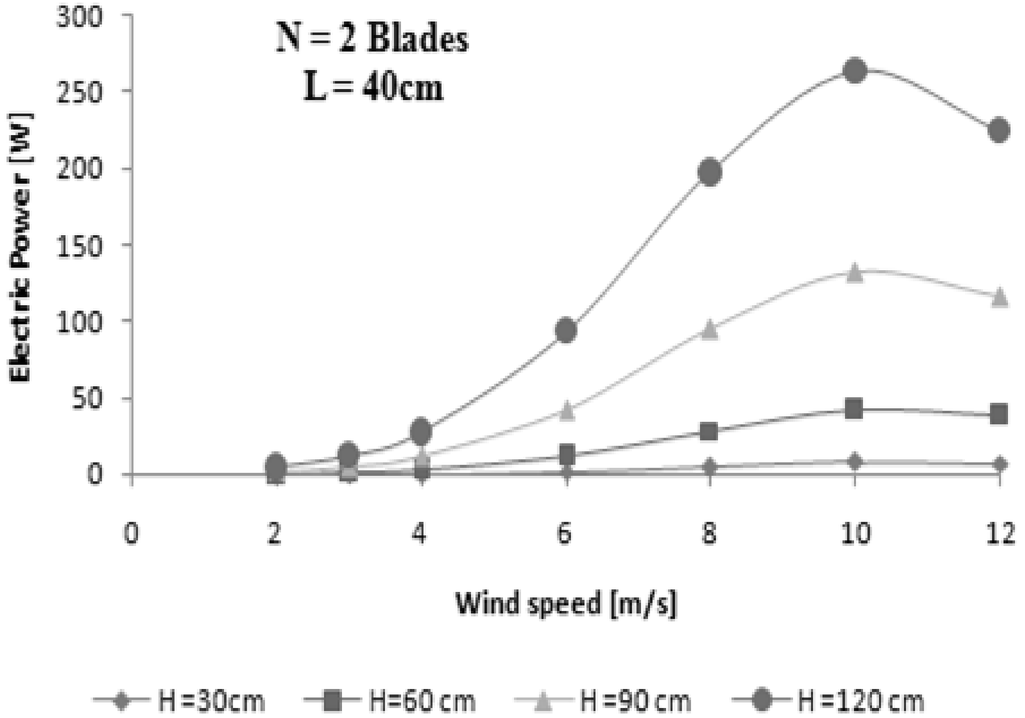

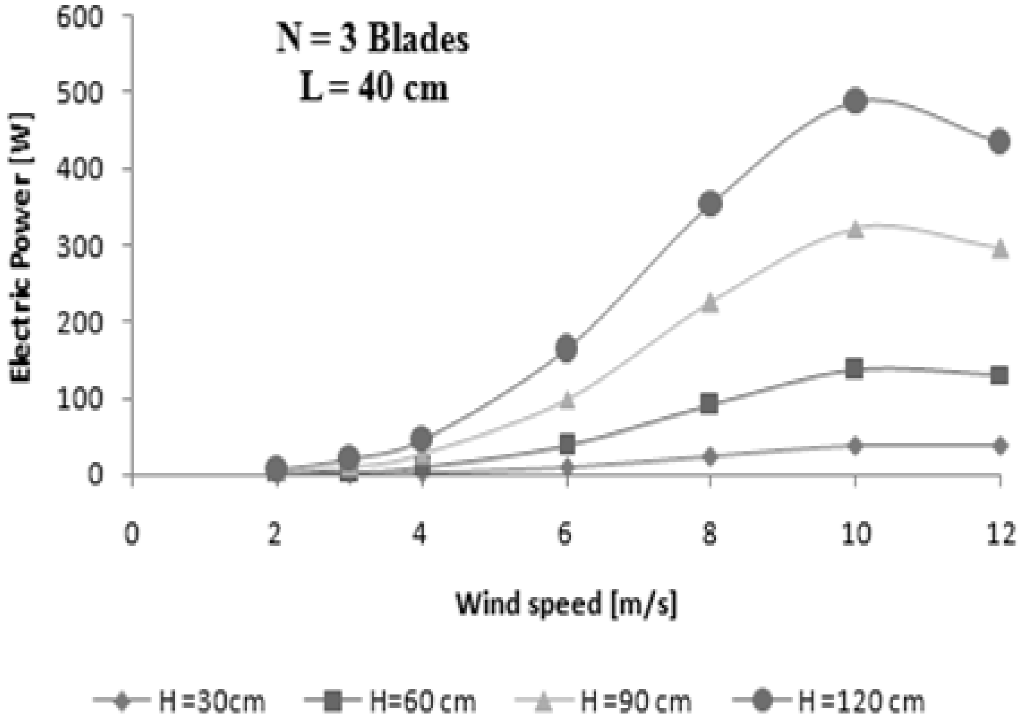

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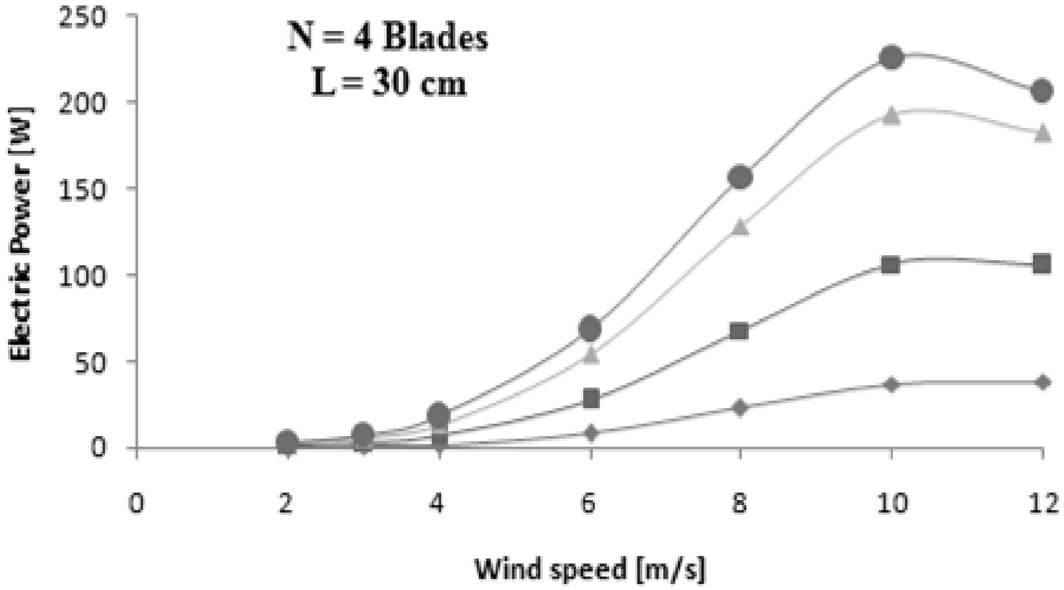

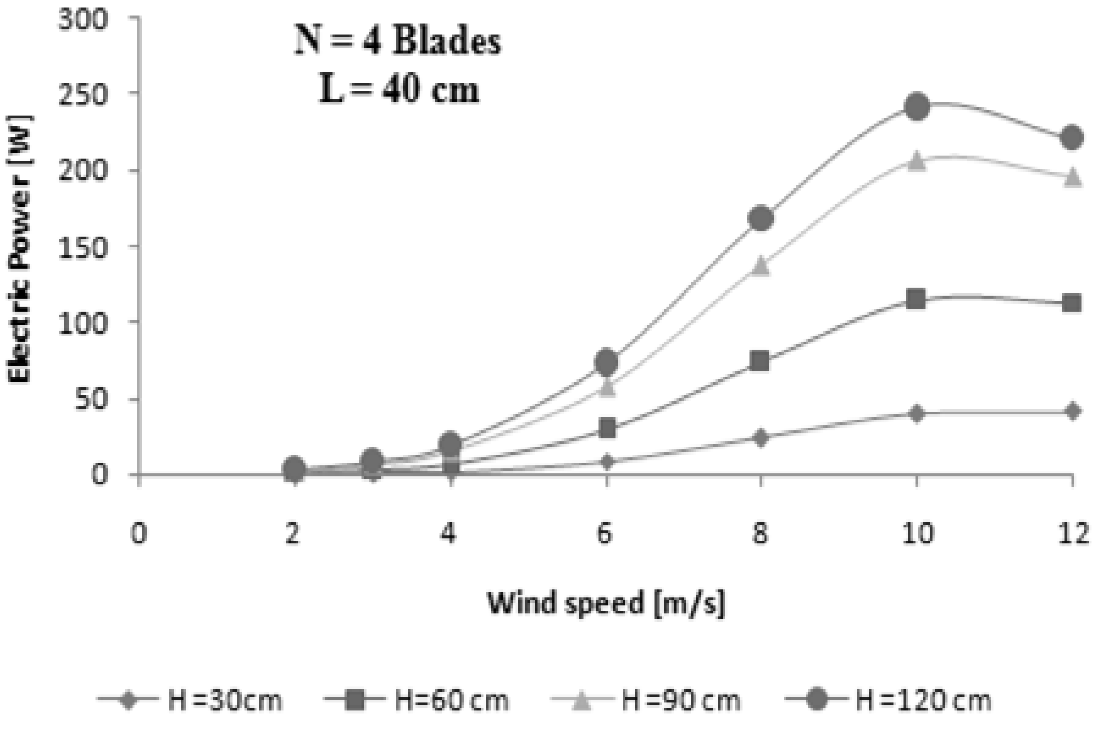

Figure 5.6: Continued

5.3 Capacity factor and energy production of the optimum rotor

As mentioned previously in section 3.3, the capacity of the generator is 500W. Furthermore, according to the experimental results, the 3-blade wind turbine models of 1200mm blade height and L = 400mm has maximum power at various wind speed and more stable at a wind speed of 10 m/s. Additionally, as shown in Figure 5.7, the electrical power of the this rotor is found to be approximately 500W at 10m/s. There was also no energy generation from the turbine if the wind speed is less than 2 m/s, which can considered as cut-in wind speed, on the other hand, the turbine cease its power generation at 12 m/s (cut-out wind speed). Therefore, Table 5.7 summarizes the characteristics of the wind turbine.

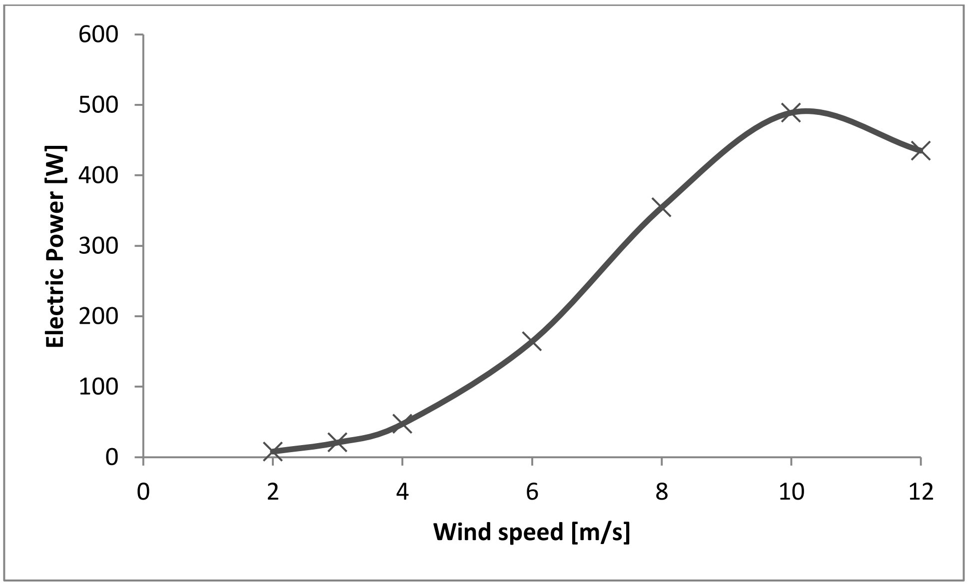

Figure 5.7: Electrical power of 3-blades rotor with L =400mm and H = 1200mm

Table 5.5: Characteristics of the wind turbine

Characteristics	Value
Power rated [W]	500
Blade diameter [mm]	200
Rotor diameter [mm]	750
Blade height [mm]	1200
Cut-in wind speed [m/s]	2
Rated wind speed [m/s]	10
Cut-off wind speed [m/s]	12

Vertical axis wind turbines (VAWTs) are good for low wind speed and can be installed on the rooftop of the building or on top of communication towers. In addition, VAWTs are able to capture incoming wind from any direction, and therefore do not need to be oriented. In addition, they are excellent in areas of turbulent wind and can self-start at low wind speeds. Therefore, building's rooftops of can be an excellent location for vertical axis wind turbines, both because the electric power generation is close to the user and because they allow taking advantages of faster winds while reducing the cost of support towers. VAWTs can be used as a grid-connected system or stand-alone system .In order to evaluate the power generating that could be produced by the wind turbine, the winds speed is calculated at different wind turbine hub height using Equation. (4.8) and (4.9). In this study, the hub height of the turbine is considered as the height of the building. In the current work, the average number of floors in the Northern Cyprus is assumed to be three floors i.e. the building height is approximately equal to 15m. Generally, the wind turbine can produce a useful power when the wind speed reaches to cut-in wind speed (v_{ci}) of the turbine. After that, the power starts to increase until the wind speed achieves the rated wind speed (v_r), at this speed, the power is equal to the rated power of wind turbine (P_r). The power generation stops when the wind speed greater than the wind cut-off wind speed (v_{co}) in order to prevent damage to the wind turbine. Consequently, the power generation of wind turbine (P_{wt}) and the total power generated (E_{wt}) over a period (t) can be expressed as following equations (Kassem et al. 2019):

$$P_{wt(i)} = \begin{cases} \mathrm{P_r}\dfrac{v_i^2 - v_{ci}^2}{v_r^2 - v_{ci}^2} & v_{ci} \leq v_i \leq v_r \\ \dfrac{1}{2}\rho A C_p v_r^2 & v_r \leq v_i \leq v_{co} \\ 0 & v_i \leq v_{ci}\ and\ v_i \geq v_{co} \end{cases} \tag{5.1}$$

$$E_{wt} = \sum_{i=1}^{n} P_{wt(i)} \times t \tag{5.2}$$

Where C_p is the performance coefficient, which can be estimated as:

$$C_p = 2\frac{P_r}{\rho A v_r^3} \tag{5.3}$$

Finally, the capacity factor (CF) of a wind turbine can be estimated as (Kassem et al., 2019):

$$CF = \frac{E_{wt}}{P_r.\, t} \tag{5.4}$$

The monthly energy production (EP) and the capacity factor (CF) for selected wind turbine were determined and summarized in Table 5.8. The EP and CF values are in the range of 0.047-4.057kWh and 0.302-26.177%, respectively. It is found that the maximum EP and CF are achieved in March in Dipkarpaz and the minimum EP and CF are recorded in December in Lefkoşa. Moreover, it is noticed that Dipkarpaz and Gazimağusa have higher values of EP and CF compared to other regions. It can be concluded that the new configuration Savonius turbine is not a good investment decision for Lefkoşa, Girne, and Güzelyurt due to low CF.

Table 5.6: EP and CF obtained from new configuration Savonius turbine for all selected regions

				EP		
	Cities	Lefkoşa	Girne	Güzelyurt	Dipkarpaz	Gazimağusa
	J	0.244	0.573	0.321	2.633	3.344
	F	0.299	0.656	0.483	2.330	3.637
	M	0.562	0.743	0.581	4.057	3.492
	A	0.693	0.411	0.566	2.532	2.202
	M	0.750	0.426	0.573	1.945	2.169
Month	**J**	1.084	0.701	0.767	2.162	2.486
	J	0.873	0.372	0.477	1.297	2.319
	A	0.739	0.349	0.454	1.152	2.280
	S	0.519	0.450	0.264	1.564	2.345
	O	0.324	0.244	0.226	1.017	2.602
	N	0.056	0.275	0.071	1.801	3.567
	D	0.047	0.475	0.167	2.452	3.783
	Annual	**5.887**	**5.581**	**4.820**	**24.216**	**33.927**
				CF		
	Cities	**Lefkoşa**	**Girne**	**Güzelyurt**	**Dipkarpaz**	**Gazimağusa**
	J	1.577	3.696	2.070	16.989	21.572
	F	2.135	4.235	3.119	15.030	23.462
	M	3.627	4.794	3.748	26.177	22.531
	A	4.620	2.652	3.653	16.336	14.209
	M	4.839	2.751	3.697	12.550	13.996
Month	**J**	7.226	4.524	4.946	13.947	16.036
	J	5.635	2.403	3.075	8.366	14.962
	A	4.766	2.253	2.929	7.430	14.712
	S	3.458	2.901	1.704	10.093	15.127
	O	2.087	1.573	1.458	6.561	16.786
	N	0.376	1.772	0.455	11.618	23.014
	D	0.302	3.066	1.097	15.822	24.404
	Annual	**3.226**	**3.058**	**2.641**	**13.269**	**18.590**

5.4 Cost and economic analysis

The wind power project cost depends on three main factors: capital cost (I), operation and maintenance system cost (C_{omr}) and the turbine life (n) (Gökçek & Genç 2009; Gölçek et al., 2007). Several methods are used to estimate the cost of the wind power project. The most common method used to calculate the wind energy costs is Levelized cost of electricity (LCOE). LCOE are expressed as given in Equation. (5.5) and (5.6) (Kassem et al., 2018).

$$\mathrm{LCOE} = \frac{\left(\sum_{t=-N}^{t=-1} \frac{I_t}{(1+i)^t}\right)_{\mathrm{construction}} + \left(\sum_{t=0}^{t=n-1} \frac{F_t + O\&M_t - D_t + T_t}{(1+i)^t}\right)_{\mathrm{production}}}{\left(\sum_{t=0}^{t=n-1} \frac{G_t}{(1+i)^t}\right)_{\mathrm{production}}} \quad (5.5)$$

$$\mathrm{LCOE} = \frac{\text{sum of cost over lifetime}}{\text{sum of electricity generated over lifetime}} \quad (5.6)$$

Where $LCOE$ is levelized cost of energy in \$/kWh or \$/MWh, I_t is investment made in the period in \$, $O\&M_t$ is Operation and Maintenance in period in %, D_t is depreciation credit in \$, T_t is the tax levy in \$, F_t is fuel cost, which is zero in wind and solar power generation and i is discount rate.

In order to evaluate the cost of kWh of the energy produced by the turbine in the selected area, the following assumption had been taken as follow:

1. The discount rate and inflation rate were taken to be 6% and 8%, respectively.
2. Machine life (n) is 20 years.
3. Electricity export escalation rate is assumed 2%.
4. Scrap value (S) was assumed 0% of the turbine price and civil work.
5. Operation and maintenance cost C_{omr} is assumed 70% of the initial capital cost of the wind turbine installation system (system price/lifetime).
6. Investment (I) is the summation of the turbine price and other initial costs which varied from country to another country. In the present study, Investment (I) is assumed to be 68%.

Table 5.9 shows the cost of the wind turbine based on the current price of the components of the optimum turbine. According to the market price, the price of small-axis wind turbines is varied between \$1000 to \$3000, which depends on several factors. Therefore, this design is simple and cheap.

Table 5.7: Cost of the new configuration of Savonius turbine

Devices and Materials	Cost [$]
Blade of the rotors, shaft and steel housing	100
Gearbox (1:10)	250
Wind power generator with a capacity of 500W	300
Total cost	**650**

The annual energy consumption of a small household is found to be 3500 kWh (Dondariya et al., 2018). The amount of electricity from the wind turbine can be produced depends on the wind speed of the selected region. Therefore, the wind speed measurements of the studied region and the power curve of the selected wind turbine are the most important factors for designing any wind farm project in the selected region. This theoretical design is used to obtain the nominal capital cost, which can help to make a feasibility study for the present research. The wind turbine number that can be installed in the location is estimated based on the distance between the turbines i.e. 6 to 9 times the diameter of the horizontal axis wind turbine and 3 to 5 times the diameter of the vertical axis wind turbine (Al Zohbi et al., 2015). In this study, the rooftop area for the small household is assumed to be 70 m^2. As a result, the possible number of wind turbines that can be installed at the roof is 12 turbines, i.e,.The total capacity of this project is 6kW and initial cost of the project is $7800. The suggested distribution of the wind turbines on the rooftop area is shown in Figure 5.8.

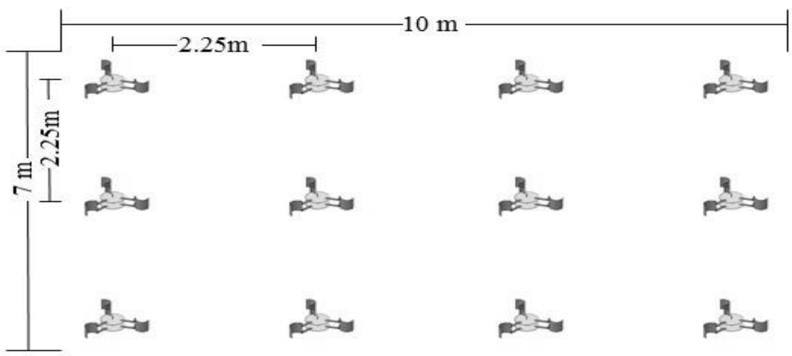

Figure 5.8: Recommended distribution of the wind rotor on the rooftop area

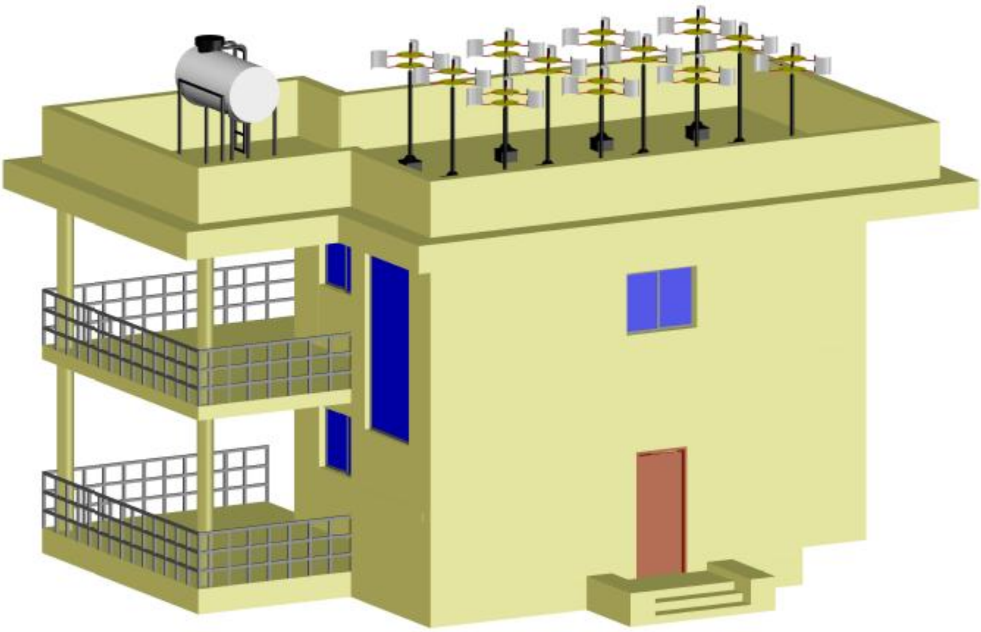

Figure 5.8: Continued

Moreover, the economic performance of 6kW wind project for studied location is presented in Table 5.10 the results showed that the proposed 6kW wind project is very promising in Gazimağusa and Dipkarpaz due to the obtained results of economic performance. In addition, Table 5.10 provides a very good insight on the economic viability of the project in the studied locations especially in Gazimağusa and Dipkarpaz. Furthermore, the wind project in Gazimağusa is an economical option because of higher values of Net Present Value and Annual life cycle savings as well as lower values of LCOE value compared to Dipkarpaz. Moreover, the result showed that wind project is not visible in Lefkoşa, Girne and Güzelyurt due to the negative value of Net Present Value and higher LCOE compared to feed-in-tariff (Kassem et al., 2019).

Table 5.8: Performance of 6kW wind projects

Region	Electricity exported to grid [kWh]	Electricity export revenue [$]	CF [%]	Net Present Value [$]	Simple payback [Year]	LCOE [$/kWh]	Annual life cycle savings [$/year]
Lefkoşa	1577	158	3	-6645	>project	0.405	-447
Girne	1577	158	3	-6645	>project	0.405	-447
Güzelyurt	1577	158	3	-6645	>project	0.405	-447
Dipkarpaz	6833	683	13	1189	11.4	0.104	104
Gazimağusa	8410	841	19	3346	9.3	0.085	292

CHAPTER 6
CONCLUSIONS

6.1 Conclusions

The objective of this study was to investigate the potential of wind energy resource in Cyprus. For this purpose, wind speed data of five urban regions in Northern Cyprus were analyzed over a six-year period from 2010 to 2016. Moreover, an experimental study has been carried out in order to design and improve the performance and increase the efficiency of new configuration of Savonius wind rotors. In order to investigate the blade geometries and overlap effect, the rotors were tested using a subsonic open test section wind tunnel. The significant findings are summarized below:

- The highest monthly mean wind speed of 7.2 m/s arises in December 2013 at Gazimağusa, while the lowest mean wind speed of 1.1 m/s occurs in September 2016 at Güzelyurt.
- Among the regions, it is found that Gazimağusa and Dipkarpaz have the higher average wind speed values compared to other regions.
- It is found that the mean annual wind speed at Gazimağusa and Dipkarpaz in the period from 20010 to 2016 was 4.7 and 4.1 m/s, respectively.
- It is found that 2W has the lowest KS compared to 3W and it is considered as the best distribution for examining the wind speed characteristics for Girne and Dipkarpaz. In addition, the results show that 3W describes the wind characterizations of Lefkoşa, Güzelyurt, and Gazimağusa better than the 2W distribution due to a minimum value of KS.
- ults showed that the wind power desnities are varied between The res These result indicated that the wind power in .^{2}and 60.08 W/m ^{2}W/m7.47 scale -Northern Cyprus is classified as poor wind power. Therefore, a small ergy in Northern part of wind turbine could be used to export the wind en .Cyprus

- The torque of the newly developed Savonius-style turbine increases with increase in free stream wind velocity up to 12 m/s. However, this increases the loading on the turbine blades, which will reduce the performance of the turbine.
- It is concluded that a four-bladed turbine should have about double or more weight to complete full rotation compared to the two- and three-bladed turbines of the same size; but a four-bladed turbine achieves a pushing power that is nearly four times that of the two- bladed turbine and double that of the three-bladed turbine of the same size.
- It is concluded that the optimum value of wind speed is 10 m/s. In fact, it was observed during the tests that the turbine with the largest number of blades (4 blades) started shaking violently at higher wind speeds. This shows that at high wind speeds, turbines with four and larger numbers of blades are unstable. This may reduce the performance of the turbine, and it may break down.
- With the newly developed Savonius-style turbine a noticeable improvement in the maximum power is observed over the other models. The overall performance of the newly developed modified Savonius-style turbine is found to be superior to that of the conventional Savonius wind turbine.
- The new configuration Savonius turbine (3-bladed rotor with height of 1200mm) is not a good investment decision for Lefkoşa, Girne, and Güzelyurt due to low CF
- The wind project in Gazimağusa is an economical option because of higher values of Net Present Value and Annual life cycle savings as well as lower values of LCOE value compared to Dipkarpaz.
- The result indicated that wind project is not visible in Lefkoşa, Girne and Güzelyurt due to the negative value of Net Present Value and higher LCOE compared to feed-in-tariff.

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APPENDICES

Appendix1: Monthly wind direction (D.) with the greatest frequency (F.) for each region

Region	Month	2010		2011		2012		2013		2014		2015		2016	
		F.	**D.**	**F**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**
	J	17.1	S	15	NE,E	18.5	N	16.6	N	14.6	S	17.3	W	19.8	N
	F	19.8	NW	16.8	SE	19.9	W	17.5	NW	15.7	N	17.3	NE	19.8	NW
	M	18.1	NW	15.7	SW	20.7	E	24.6	N	24.6	N	20.7	N	22.6	W
	A	17.1	E	19.8	N	19.9	NW	18.2	N	16.5	NW	20.4	NW	18.1	N
	M	18.1	SE	15.9	SE	18.2	NW	16.6	E	15.5	NW	16.2	W	18.2	NW
	J	17.2	SE,E	16.7	E	19.8	E	21	N	17.6	W	15.4	NW	16.9	W
	J	16.7	E	16.3	N	19.6	N	15.3	N	16.2	W	13.9	N	20.3	SE
Lefkoşa	**A**	14.7	SW	14.7	S	17.5	N	13.9	N	13.3	S,NW	14.7	NW	14.8	E
	S	16.6	SW	12.7	SE	12.8	W	17.2	N	15.2	W	14.3	NE	16.4	W
	O	17.5	SW	16.7	NE	30.8	NE	17.8	NE	22	SE	14.9	N	16.6	W,NW
	N	10.8	E	20.3	NE	14.2	N	14.8	E	13.6	E	17	N	19.3	N
	D	12.8	E	19	E	20	W	24.4	N	18.1	N	19.2	N	20	NW
	J	19.5	SE	15.6	SE	20	SE,E	17.8	NW	19.4	N	19.5	S	27.9	NW
	F	28.2	WSW	18.1	NW	23.2	E	17.8	NE	16.9	E	17.8	S	16.9	NW
Girne	**M**	28.8	SSE	16.7	SW	22.3	S	30.1	E	22.9	SE	20.4	E	20.5	NE
	A	17.2	NW	21.9	NW	18.5	E	21.7	NE	15.8	NW	15.8	N	15	NE
	M	17.6	N	14.3	NW	17.6	E	18.2	E	16.8	E	16.3	E,E	16.5	E
	J	17.3	NW	16.4	NW	18.5	SW	16	NW	18.6	E	15.1	E	14.7	NW
	J	13.1	NW	13.5	NW	15.8	S	13.9	NE	17.3	E	10.3	E	12.3	N
	A	12.5	NW	12	NW	14.3	E	11.9	NW	11.5	E	15.1	E	10.9	E
	S	15.2	NW	13.5	E	12.4	NW	15.7	N	16.5	E	15.3	E	16.7	N
	O	19.3	NW	16.1	S	20	S	18.2	NW	17	SE	18.3	SE	14.5	E
	N	14.3	SE	32.6	S	20	W	13.1	W	15.8	E	15.7	S	19	S
	D	22	E	19.7	SE	20	N	22.3	SE	18.8	E	19.8	SE	24.6	SE
	J	18.1	ESE	13.6	NE,SE	16.5	NW	17.2	NW	15.7	SE	16.1	NW	18	N
	F	19.9	NW	17.4	NW	20	NW	16.9	NW	13.8	E	16.7	SE	15.3	N
	M	17.1	ESE	19.2	NW	20.3	S	23.2	NW	19.5	N	19.4	N	17.4	NNW
	A	19.1	NNW	22.3	W	21.2	SE	18.8	NW	16.5	N	18	N	17.3	N
	M	19.9	NNW	16	NE	18.4	N	16.1	N	19.9	N	18.2	N	17.2	N
Güzelyurt	**J**	18.5	NNW	18.7	N	17.9	SE	18.6	N	19.2	SE	17.4	N	17.1	N
	J	13.7	N	13.9	N	12.3	SE	17.4	N	20	N	11.7	N	13.8	N
	A	11.2	NNW	13.8	N	19.9	S	16.3	N	14.9	N	17.3	N	13	N
	S	16.2	NNW	12.5	N	15.2	N	17.5	N	17	N	17.1	N	16.3	N
	O	15.3	NW	15.9	NW	14.7	NW	15.3	N	16.1	N	13.8	N	15.8	N
	N	14.8	SE	10.1	SE,NE	10.7	SE	15.1	SE	12.9	N	13.9	N	14.6	SE
	D	13.8	S	20.7	N	20.8	NW	15.9	N	18.6	SE	14.5	S	18.6	N
	J	17.1	S	15	NE,E	18.5	N	27	N	19.5	E	31.9	N	23.8	W
	F	19.8	NW	16.8	SE	19.9	W	21.3	SW	17.1	E	24.9	N	20.5	SE
	M	18.1	NW	15.7	SW	20.7	E	30.8	E	29.7	N	23.9	NW	24.1	E
	A	17.1	E	19.8	N	19.9	NW	23.1	N	16.6	N,NW	20.4	NW	17.1	SW
Dipkarpaz	**M**	18.1	SE	15.9	SE	18.2	NW	19.2	NW	17	E	17.2	E	17	NW
	J	17.2	SEE	16.7	E	19.8	E	20.1	N	17.7	NW	19.7	N	16.6	NW
	J	16.7	E	16.3	N	19.6	N	13.9	NE	15	NW	13.9	NW	13.7	NW
	A	14.7	SW	14.7	S	17.5	N	13.2	E	15.3	SW	14.9	N	11.4	SW
	S	16.6	SW	12.7	SE	12.8	W	16.6	E	19.4	NE	20.8	NE	19.8	N
	O	17.5	SW	16.7	NE	30.8	NE	19.4	E	21.1	N	24.9	NW	19.5	NW
	N	10.8	E	20.3	NE	14.2	N	15.3	E	15.7	E	22.7	N	15.3	SW
	D	12.8	E	19	E	20	W	23.9	E	20.4	SE	23.1	N	14.2	N

Appendix1: continued

Gazimağusa	**J**	17.1	S	15	NE,E	18.5	N	16.6	N	14.6	S	17.3	W	19.8	N
	F	19.8	NW	16.8	SE	19.9	W	17.5	NW	15.7	N	17.3	NE	19.8	NW
	M	18.1	NW	15.7	SW	20.7	E	24.6	N	24.6	N	20.7	N	22.6	W
	A	17.1	E	19.8	N	19.9	NW	18.2	N	16.5	NW	20.4	NW	18.1	N
	M	18.1	SE	15.9	SE	18.2	NW	16.6	E	15.5	NW	16.2	W	18.2	NW
	J	17.2	SE,E	16.7	E	19.8	E	21	N	17.6	W	15.4	NW	16.9	W
	J	16.7	E	16.3	N	19.6	N	15.3	N	16.2	W	13.9	N	20.3	SE
	A	14.7	SW	14.7	S	17.5	N	13.9	N	13.3	S,NW	14.7	NW	14.8	E
	S	16.6	SW	12.7	SE	12.8	W	17.2	N	15.2	W	14.3	NE	16.4	W
	O	17.5	SW	16.7	NE	30.8	NE	17.8	NE	22	SE	14.9	N	16.6	W, NW
	N	10.8	E	20.3	NE	14.2	N	14.8	E	13.6	E	17	N	19.3	N
	D	12.8	E	19	E	20	W	24.4	N	18.1	N	19.2	N	20	NW

Appendix2: Annual wind direction (D.) with the greatest frequency (F.) for each region

Region	2010		2011		2012		2013		2014		2015		2016		Whole (2010-2016)	
	F.	**D.**	**F**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**	**F.**	**D.**
Lefkoşa	19.8	NW	20.3	NE	30.8	NE	24.6	N	24.6	N	20.7	N	22.6	W	30.8	NE
Girne	28.8	WSW	32.6	S	23.2	E	30.1	E	22.9	SE	20.4	E	27.9	NW	32.6	S
Güzelyurt	19.9	NW	22.3	W	21.2	SE	23.2	NW	20	N	19.4	N	18.6	N	23.2	NW
Dipkarpaz	19.8	NW	20.3	NE	30.8	NE	30.8	E	29.7	N	31.9	N	15.7	SW	31.9	N
Gazimağusa	19.8	NW	20.3	NE	30.8	NE	24.6	N	24.6	N	20.7	N	22.6	W	30.8	NE