DECEMBER 2017 M.Sc. in Physics Engineering AHMED ABDALAZIZ ALHUSHMAWI

UNIVERSITY OF GAZİANTEP

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EXPERIMENTAL PERFORMANCE INVESTIGATION OF ELECTRICAL ENERGY PRODUCTION SYSTEM BY USING VERTICAL BARREL OF TWO AND FIVE BLADES FROM WIND ENERGY IN GAZIANTEP CONDITION

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BY

AHMED ABDALAZIZ ABDALWAHAB ALHASHMAWI

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Supervisor

Assoc. Prof. Dr. Rabia Güler Yıldırım

by

Ahmed Abdalaziz Abdalwahab ALHASHMAWI

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Ahmed Abdalaziz Abdalwahab ALHASHMAWI

ABSTRACT

EXPERIMENTAL PERFORMANCE INVESTIGATION OF ELECTRICAL ENERGY PRODUCTION SYSTEM BY USING VERTICAL BARREL OF TWO AND FIVE BLADES FROM WIND ENERGY IN GAZIANTEP CONDITION

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Vertical-axis wind turbines (VAWTs) possess several advantages over the conventional horizontal-axis type. Savonius turbines are drag-based routers which operate due to a pressure difference between the advancing and retreating blades. These turbines are simpler in design, less expensive to install, non-dependent of wind direction, and more efficient at lower wind speeds. This makes it suitable for generating electricity in many countries.

This work is a study of the performance of the Savonius rotor which contains two and five blades made from barrels of oil under the normal weather conditions of the Turkish city of Gaziantep. This rotor has the best self-starting at low wind speed, under any load generator. Where begins rotation of 20 RPM at 2 m/s wind velocity. We also find the maximum power coefficient at the tip speed ratio and the amount of voltages generated by the generator at different wind speeds to both types and know which one has the best performance.

Key Words: Vertical axis wind turbine, savonius, electric power, voltage.

ÖZET

GAZİANTEP KOŞULUNDA RÜZGAR ENERJİSİNDEN İKİ VE BEŞ KANATLARIN DARBELİK KULLANIMI İLE ELEKTRİKLİ ENERJİ ÜRETİM SİSTEMİNİN DENEYİMLİ PERFORMANS DENEYİMİ

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60 sayfa

Dikey eksenli rüzgar türbinleri, geleneksel yatay eksen tipi tipine göre birçok avantaja sahiptir. Savonius türbinleri, ilerleyen ve geri çekilen kanatlar arasındaki basınç farkı nedeniyle çalışan sürükleme tabanlı yönlendiricilerdir. Bu türbinler tasarım açısından daha kolaydır, kurulum daha az pahalıdır, rüzgar yönüne bağlı değildir ve daha düşük rüzgar hızlarında daha etkilidir. Bu, birçok ülkede elektrik üretmek için uygun olmasını sağlar.

Bu çalışma, Gaziantep'in normal hava koşullarında petrol fıçılarından yapılmış iki ve beş kanat içeren Savonius rotorunun performansının bir çalışmasıdır. Bu rotor, herhangi bir yük üreteci altında, düşük rüzgar hızında en iyi otomatik dönüşe sahiptir. 2 m / s rüzgar hızında 20 dev / dak dönüştür. Ayrıca uç devir oranındaki azami güç katsayısını ve jeneratörün farklı rüzgar hızlarında ürettiği voltaj miktarını her iki türbinde (2 ve 5-kanatlı) hesaplandı.

Anahtar Kelimeler: Dikey eksen rüzgar türbini, savonius, elektrik gücü, gerilim.

To

The greatness of a father

The generosity of a mother

The togetherness of a family

The love of a my love

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LIST OF SYMBOLS/ABREVIATIONS

VAWT	Vertical Axis Wind Turbine
HAWT	Horizontal Axis Wind Turbine
A	Rotor area
D	Rotor diameter
H	Rotor height
d	Blade diameter
$\boldsymbol{v}$	Wind velocity, m/s
N	Rotational speed, RPM
$\boldsymbol{\rho}$	Air density, kg/m^3
$\boldsymbol{\omega}$	Angular velocity, rad/Sec
$\boldsymbol{\lambda}$	Tip speed ratio
T	Torque
$\boldsymbol{P}_a$	wind power
$\boldsymbol{P_e}$	Electrical power
I	An electrical current
V	Voltage
AC	Alternating Current

DC	Direct Current
C_p	Power Coefficient

CHAPTER 1

INTRODUCTION

1.1. General

Traditional energy has become expensive and an environmental hazard, therefore; it is necessary to find an alternative energy source from renewable energy sources to reduce the high usage of fossil fuels and also to reduce the damage caused by CO2 emissions. A lot of countries have gone to find new energy sources to escape the escalating disadvantages of fossil fuels and to improve alternative clean energy sources more than ever before.

Wind energy is a good source of renewable energy, because of its availability throughout the year; it is also considered pollution free to the environment.

Turkey is one of the countries that tries hard to develop renewable energy sources, especially after the expansion of the Turkish economy in recent years, which led to increasing in the consumption of primary energy. Over the last 10 years a rise in the share of energy production has been seen from renewable sources [1], as shown in Figure 1.1.

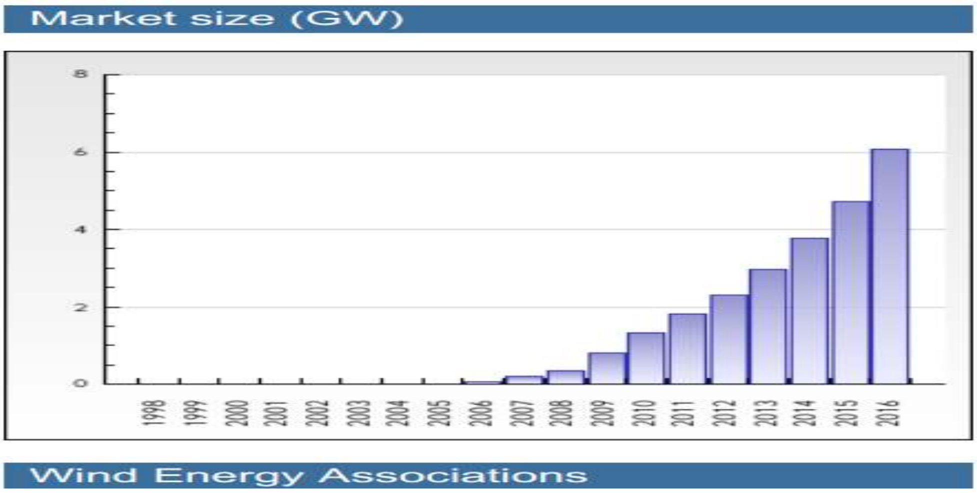


Figure 1.1 Production capacities in Turkey *[2]*.

Turkey is considered a windy country, this made it capable to meet part of the country's high energy demand due to the geographic location and having a lot of seas like Sea of Marmara, Aegean Sea and the Mediterranean Sea, also there is considerable potential for wind power utilization compared to other regions, because of these factors, wind power is the most effective renewable energy source in Turkey. In recent years there has been a rapid development in the wind energy field.

At 2011, the capacity of wind power plants reached 1.729 GW in Turkey and it will reach 20 GW in 2023 according to the general wind energy policy of Turkey [3], as shown in Figure 1.2.

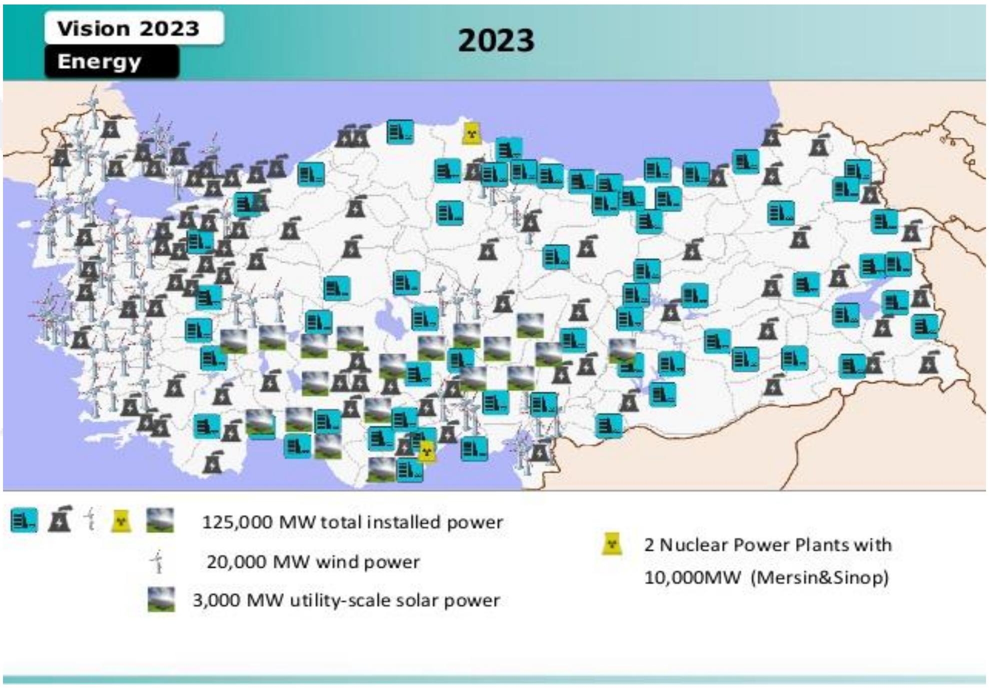


Figure 1.2 Turkey's visions of energy by 2023 [4].

1.2. Alternative Energy

There's a lot of alternative energy sources for example Bioenergy where this energy can be obtained from the remains of forests, plants and livestock which directly converted to electricity production.

Solar power through the use of solar cells, we can convert the energy produced from solar radiation into electricity, hydropower, which can provide electricity from rivers, dams and the transfer of water from high to low areas, geothermal energy Such as drilling wells to generate electric energy.

Ocean Energy through the potential kinetic energy of thermal and chemical seawater tides and other processes we can produce electricity, wind energy which is the subject of the current study that will investigate in this thesis in an extended manner. This alternative energy could fill the world's electricity needs in the future for about half a century or more [5].

1.3. Wind energy

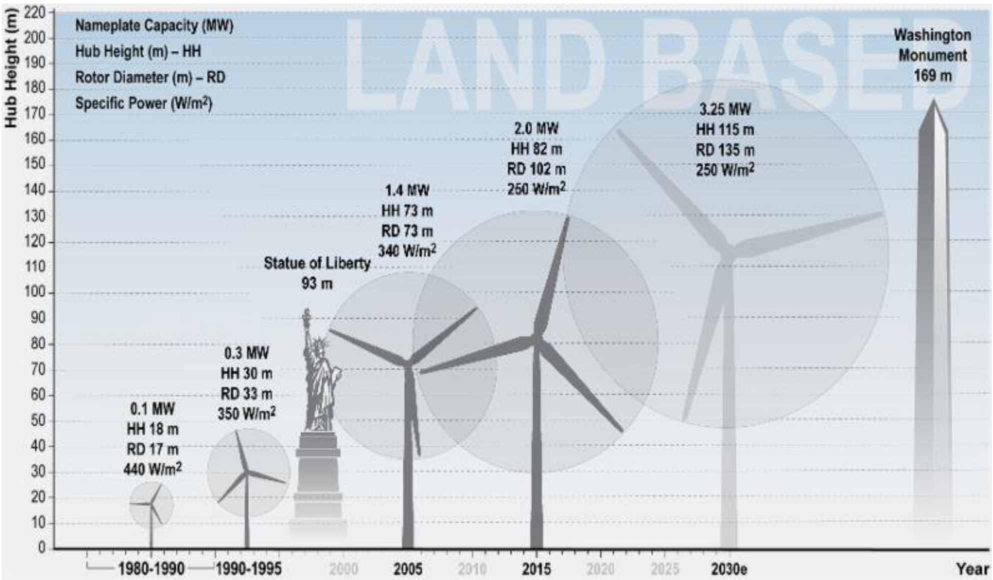
Wind energy was used in the distant past to provide mechanical energy such as pumping water and grinding grain. After the oil price shock in 1970, the world's population need to consume more electricity and the lack of possibility to generate in some places because of the scarcity of resources such as fossil fuels, wind power has returned to the surface again to generate electricity rather than mechanical energy [6].

A marked increase has been seen in the use of wind power in the last two decades, this is a proof that wind energy is one of the most common renewable sources of energy after solar energy. The first one who built a wind turbine to generate electricity is the scientist Poul Lacour in 1891, then it developed gradually from its historical idea that began as a simple wind power, when it was erected on the mountain passes, through the east of San Francisco and northeast of Los Angeles. The first of these huge wind farms is composed of 50 KW wind turbines. Thus, the volume of interest increased over the years to about 200 kW in the 1980s.

Europe has benefited from the slowdown in financial support of the USA, as well as India in the 1990s where each of them relied on a special incentive, for example, in Europe, which relied on nutrition tariffs in the reform of renewable energy generation. In India, they relied on tax deductions for investments in wind energy until the development of wind power reaches up to 1.5 MW wind turbines at the end of the twentieth century [7].

According to a report published by Nature Energy, which was analyzed by the opinions of 163 experts specialized in wind power around the world. Where they expected a lower wind power cost in the future, which can be reduced by 24 to 30 % in 2030 due to the remarkable progress in turbine technology. As each turbine gets bigger and produces more energy, the cost of building that turbine will be easier to offset by the power it produces [8]. As shown in Figure 1.3 a, b.

(a)



(b)

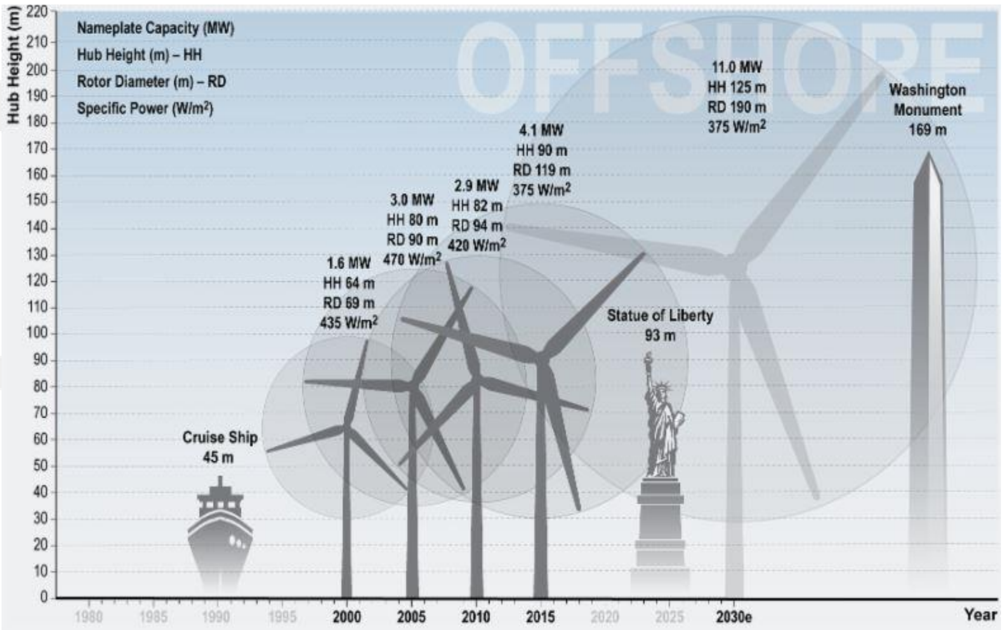


Figure 1.3 a,b The stages of development of land based and offshore turbines [8].

Wind technology does not have to be limited to the high-scale production. In some places, especially the urban cities, there's a small wind turbine that meets the limited needs. This made everyone have the ability to make such turbines and access renewable sources easily. Where there is a classification based on the capacity produced and different sizes such as utility-scale, it is a large turbine with a capacity of 900 kW to 3 MW, industrial-scale, ranging from 50 kW to 250 kW with a medium size and residential-scale, its capacity ranges from 400 watts to approximately 50 kW with a small size turbines [9].

1.4. Wind Turbine Types

The basic principle of wind turbine work is to convert wind energy into mechanical energy and then convert mechanical energy to electricity. Most wind turbines are classified into three types:

1. The first type of turbines is based on the direction of the axis of rotation, such as horizontal turbines and vertical turbines.
2. The second is categorized according to the method of power generation, such as micro, small, medium and large turbines.
3. The third type of turbines is dependent on the factor of wind forces, such as drag turbines or lift turbines.

Each of these types has advantages and disadvantages [10].

There is a good efficiency of both horizontal (HAWT) and vertical (VAWT) axis wind turbines. But the (HAWT) efficiency is better than the (VAWT) and therefore it's the most widespread in the world.

(HAWT) has a rotor, gearbox and generator at the top of the tower and also has the ability to sway to be facing the wind coming towards the turbine. This movement towards the wind reduces the energy losses when the turbine is connected to the generator. On the other hand (VAWT) never rely on the direction of the wind and placed near to the surface of the ground making it easier to maintain.

Both types of wind turbines have the same general components:

1- A rotor converts wind energy to mechanical power.
2- A tower to support the rotor.
3- A gearbox to adjust the rotational speed of the rotor shaft for the electric generator or the pump.
4- A control system to presents the operation of the wind turbine in automatic mode on the screen, including starting and stopping button.
5- A foundation (sometimes supported by sling wires) to prevent the turbine from falling down when high wind blows [11].

The factors that made horizontal axis wind turbines more used and efficient are:

- Control rotor speed and output by blade pitch control.

- Durability in wind speeds with excess and maximum due to pitching.
- The blades can be optimized for aerodynamic extraction to get higher efficiency.
- The higher place of the tower altitude lead to an increase in wind speed about 20%, sometimes for every 10 meters of [12].

The disadvantages of horizontal axis wind turbines:

- The costs of building high towers and transportation costs are very high.
- Producing electronic noise affecting the sites of radars nearby.
- Yaw mechanism needed to control the conversion of the blades towards the wind coming to the turbine [13].

1.5. Wind Energy Utilization

Despite of the rapid increase in the use of wind as a source of electricity in the world, it is still limited to meet the needs of energy, whereas only a few regions are using it.

Because of the increasing population, high energy demand, persistent concern about resource scarcity and global climate change, there has been a strong incentive to find an alternative to energy. The only hope other than fossil fuels is solar energy and wind power. In order for wind energy to have a greater contribution to electricity generation, it must be more efficient.

2015 was an ideal year for wind power, where the percentage increases in the market by about 22% from the year 2014 by about 63 GW, making the world total production about 433 GW, nearly half of the world's wind energy produced in the last five years.

In more than 80 countries, commercial wind turbines activities have seen widespread at the end of 2015. There are also 26 countries with more than 1 GW output, according to one of the reports. Wind energy has generated electrical power more than any other technology in 2015 [14], as shown in Figure 1.4.

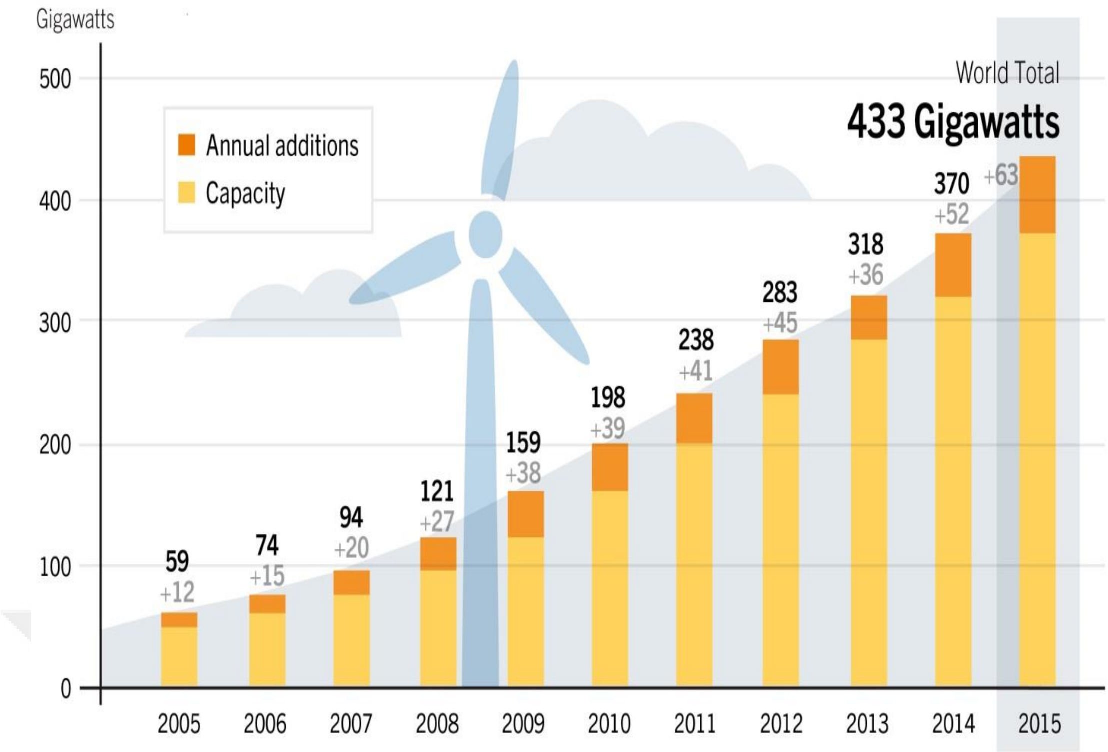


Figure 1.4 Wind Power Global capacity and Annual Additions, 2005-2015 [14].

China leads the list of new enterprises followed by the United States, Germany, Brazil and India. Other countries, among the top 10 countries are Canada, Poland, France, UK and Turkey.

Turkey is expected to add more than 4.7 GW by the end of 2015. China has added new capabilities, which alone represent nearly half of the world's additions. By the end of 2015, Denmark, Sweden, Germany, Ireland and Spain are among the leading countries of total wind power per capita [14],as shown in Figure 1.5.

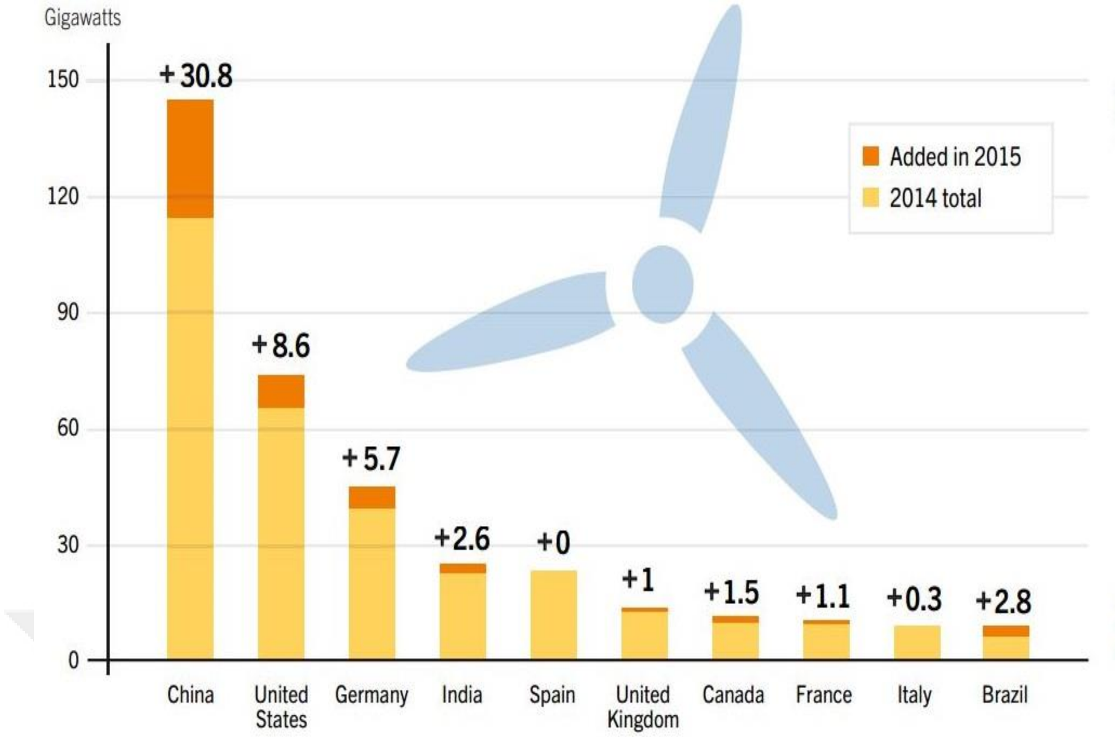


Figure 1.5 Wind Power Capacity and Additions, Top 10 countries [14].

1.6. Research Motivations

While the gross consumption of electricity in 2010 was 21.434 GWh, the percentages of production climbed by 2.7 % in 2015 reaching 264.150 GWh. Turkey imported 7,411 GWh of electricity and exported 2,951 GWh in 2015. These numbers show that the Turkish energy market is still in substantial need for energy investments.

Power generation percentages based on energy source are shown in the chart below, derived from the information gathered from the Turkish Ministry's Overview [15].

Table 1.1 Power Generation in Turkey Based on Energy Source (GWh) [15].

Year	Thermic	Hydraulic	Geothermic + Wind + Solar	Total	Increase (%)
2002	95,563	33,684	153	129,400	5.4
2003	105,101	35,330	150	140,581	8.6
2004	104,464	46,084	151	150,698	7.2
2005	122,242	39,561	153	161,956	7.5
2006	131,835	44,244	221	176,300	8.9
2007	155,196	35,851	511	191,558	8.7
2008	164,139	33,270	1,009	198,418	3.6
2009	156,923	35,958	1,931	194,813	-1.8
2010	155,828	51,796	3,585	211,208	8.4
2011	171,638	52,339	5,418	229,395	8.6
2012	174,872	57,865	6,760	239,497	4.4
2013	171,812	59,420	8,921	240,154	0.3
2014	200,417	40,645	10,901	251,963	4.9
2015	177,866	66,903	14,922	259,690	3.1
Ended March 2016	43,664	17,405	4,711	65,781	-

For all the data obtained from the Energy Market Regulatory Authority (EMRA), the percentages of energy sources used for electricity generation in 2015 were natural gas (37.8%), coal (28.4%), hydro (25.8%), wind (4.4%), fuel oil, diesel and naphtha (1.6%), geothermal (1.3%) and biogas (0.6%). So far, wind power in Turkey has not achieved the ambition of everyone's expectations. [16], as shown in Figure.1.6.

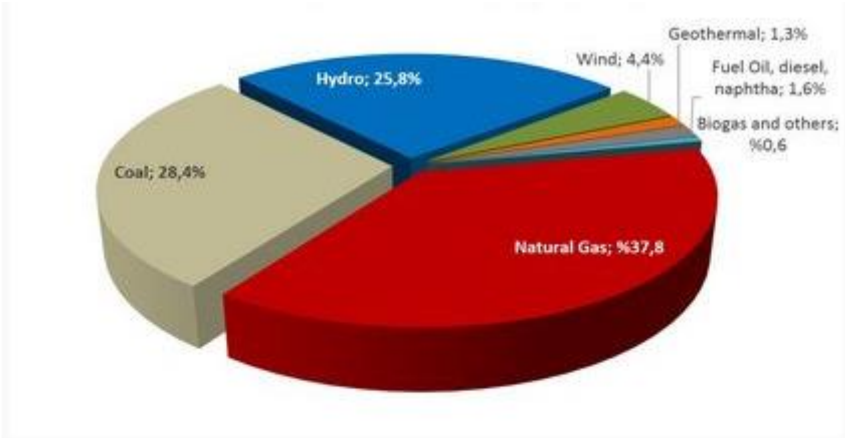


Figure 1.6 Electricity generation in Turkey [16].

In light of the large consumption and concern of non-renewable sources of energy which are threatening the purity of the environment because of CO2 emissions and other disadvantages. Through the current experimental research, a highlight is presented to get an electricity from a source that is cheap, available and has no impact on the environment, it does not require a large design or construction or high cost and can be used in urban areas. It's a manufacturing of a vertical axis wind turbine (VAWT) using a normal barrel.

1.7. Work objectives

The main objective of this research is to study the aerodynamics characteristics for two Savonius wind turbine models and to study the two models efficiency in the electrical power generating to contribute in enhancing the performance of these two models. To achieve these goals the following arrangement must be done:

1. Designing and manufacturing two and five blades Savonius wind turbine models.
2. Calculating the speed of wind blowing on the blade, also measuring rotational speed of the turbine.
3. Calculating both voltage and electrical current that generated from the generator for obtaining value electrical power.
4. Calculating both power coefficient and tip speed ratio by mathematical equations to compare them with experimental results.

1.8. Organization of the thesis

This research contents five chapters, Chapter one presents a general introduction of renewable energy, also it presents a general view of wind energy and its international uses in the world in general and its uses in Turkey specially with mentioning a statistics and reports of development and growing of the usages of wind energy around the world and motivation behind using his type of energy.

Chapter two includes a brief of some of the researcher's studies about the performance and design of both Savonius and Darrius vertical axis wind turbine types by different circumstances.

Chapter three provides a detailed explanation of designing the turbine models, experimental methodology and the mathematical equations to check the validity of the numerical number.

Chapter four discusses the experimental results and calculation, Chapter five includes a conclusion of the experimental study and future works.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Since the early recorded history, people have harnessed the wind energy. Wind energy propelled boats along the Tigris, Euphrates and Nile rivers as early as 5000 B.C. By 200 B.C., simple windmills in China were used to push water, while vertical-axis windmills with lace cane sails were grinding grain in Persia and in the Middle East. By the 11^{th} century, people in the Middle East used windmills extensively for food production. When settlers took this technology to the New World in the late 19^{th} century, they began using windmills to pump water for farms and ranches and later they used it to generate electricity for homes and industry.

During world war two, the largest wind turbine known in the 1940's was a 1.25 megawatt turbine that located on a Vermont hilltop well-known as Grandpa’s Knob, fed electric power to the local utility network. Wind electric turbines persisted in Denmark till the 1950's, but were ultimately sidelined due to the availability of cheap oil and lower energy prices.

The oil shortages of the 1970's changed the energy picture for the U.S. and the world. It created an interest in alternative energy sources, paving the way for the re-entry of the wind turbine to generate electricity.

2.2. History Vertical Axis Wind Turbine

The first to invent Vertical Axis Wind Turbines was Persia, it was used by people living in eastern part of Persia In the region of Sistan, which is famous for the high winds of 45 m/s (100 mph), also in the 10^{th} century it was known as a source of mechanical energy such as the windmill. These turbines were essentially drag machines with rotors, which contains a number of reed bundles or other blades on the wood frame.

The rotor is placed inside the enclosure surrounded by walls facing the coming wind, thus it generated the required torque to rotate the mill [17] [18] [19],as shown in Figure 2.1.

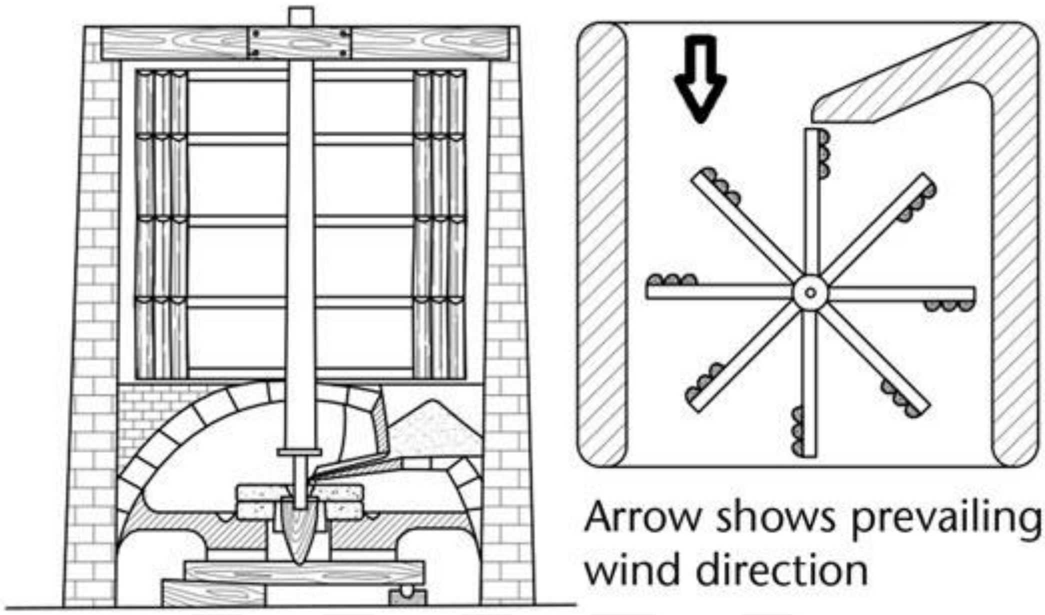


Figure 2.1 Persian windmill [20].

People used wind energy for different purposes. Some historians have suggested that the use of windmills began about 2000 BC. The ending of the 19th century is considered the old period of development, the period from the 19th century to the present time is considered the period of modern development, which wind turbines first produced to generate electricity in Denmark [18].

The Stupendous, the vertical axis windmills is more efficient than the horizontal ones. In 1400 AD the Netherlands developed a better design of horizontal machines, as shown in Figure 2.2. [21].

Figure 2.2 Design of horizontal machines in Netherlands.

As mentioned earlier, the vertical windmills are older than the horizontal axis windmills, this is due to the innovations of Savonius and Darius. The practical benefits of the vertical turbines were restored and developed in the early 20th century. Then, after the oil crisis in 1970's, many turbines were built in the United States and Germany, which continued until 1990's, on the other hand, the development of horizontal axis wind turbines was also progressing. Now in the present time, after a 20-year period of stability in developments, scientists have returned to the scene to take advantages of it, but in slow rate [22].

The basic steps in the process of developing the performance of vertical turbines through design is the possibility of understanding how the wind forces operating on wind turbines. In the 1980's, torque output and power have been averaged through an evolutionary performance of the rotor. This development was by investigating the accuracy of the model, which was lacking of some important information by changing the amounts of torque and the power to perform better during rotor rotation [23].

The end of the 19th century saw the phase of the transformation of windmills that produce mechanical energy into wind turbines that generate electricity.

This historic transition has led to the successful commercial development in small wind generators, thus studies have been carried out building large turbines. The key factor in the rapid development of airfoils which developed wind turbine performance is the evolution of the aircraft industry in the early 20^{th} century [24].

Through the construction of Darius-type turbines, vertical axis wind turbines took great interest in the United States and Canada in 1970's and 1980's. FloWind, the United States, installed many Darius turbines in wind farms that aimed to produce electricity on a commercial scale.

Hydro-Québec is a Canadian company, built a Darius turbine named Eole in 1986, for the purpose of producing electricity on the scale of megawatt. In the United Kingdom, a 500 kW H-rotor was built in 1989.

A Heidelberg motor company in Germany then manufactured a 300 kW H-rotor. In the present era, there are many companies that manufacture commercial wind turbines, Including Solwind Company, the manufacturer of vertical wind turbines located in New Zealand and also the Italian company was manufacturing the same turbines.

There are many companies in different countries have developed new designs and capabilities, including the Dutch company Turby, which built the first helical design of turbines. This approach was then followed by Russia to manufacture turbines similar to those called the Wind-Sail. [25].

2.3. Literature review on Savonius rotor

Many researches have been trying to study and develop designs of aerodynamics that gives better productivity, to benefit from wind energy in a productive way but this problem remains difficult. One of these studies was conducted on the Savonius rotors, which contained two semi-cylindrical S-shaped blades with different flow parameters.

The Savonius wind turbines are of the type of drag with very small lifting forces. The traditional Savonius rotor consists of semi-circular buckets has been opposite faces. Because of the varying pressure exerted on the progress and retreat of the blades occurs during rotation.

While the wind blows the turbine blades, two elements of the drag force are created on the surface of each blade. The first is the normal drag force (Fn) that works vertically on the blade wall. The second is the drag force (Ft) that runs along the tangent direction of each blade [26], as shown in the following Figure.2.3.

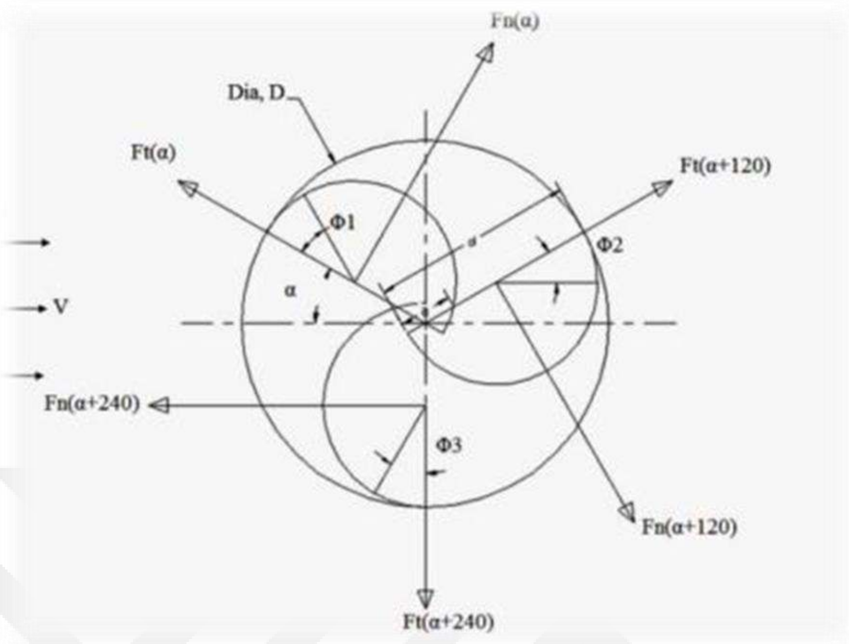


Figure 2.3 Schematic of the drag force components on model cross-section [26].

Experiments were conducted by changing the number of blades from 2 to 3 in single, two and three stage turbine systems. For semicircular and twisted blade were examined to get to the results which shown in figures 2.4 and 2.5. It was observed that the power coefficient of turbine reduced when the number of blades increased from 2 to 3 blades. Thus, with the increasing number of blades leads to low rotor performance. It can be inferred from the experimental evidence that the 2-blade system gives optimal performance. [27]

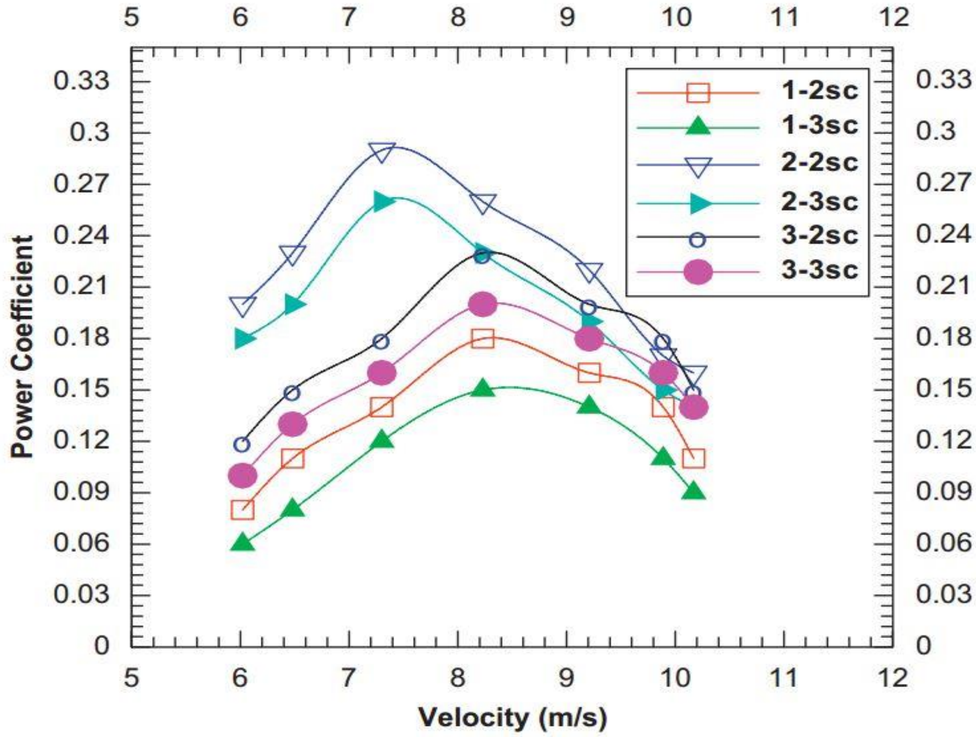


Figure 2.4 Variation of power coefficient with velocity for semicircular Savonius rotor system.

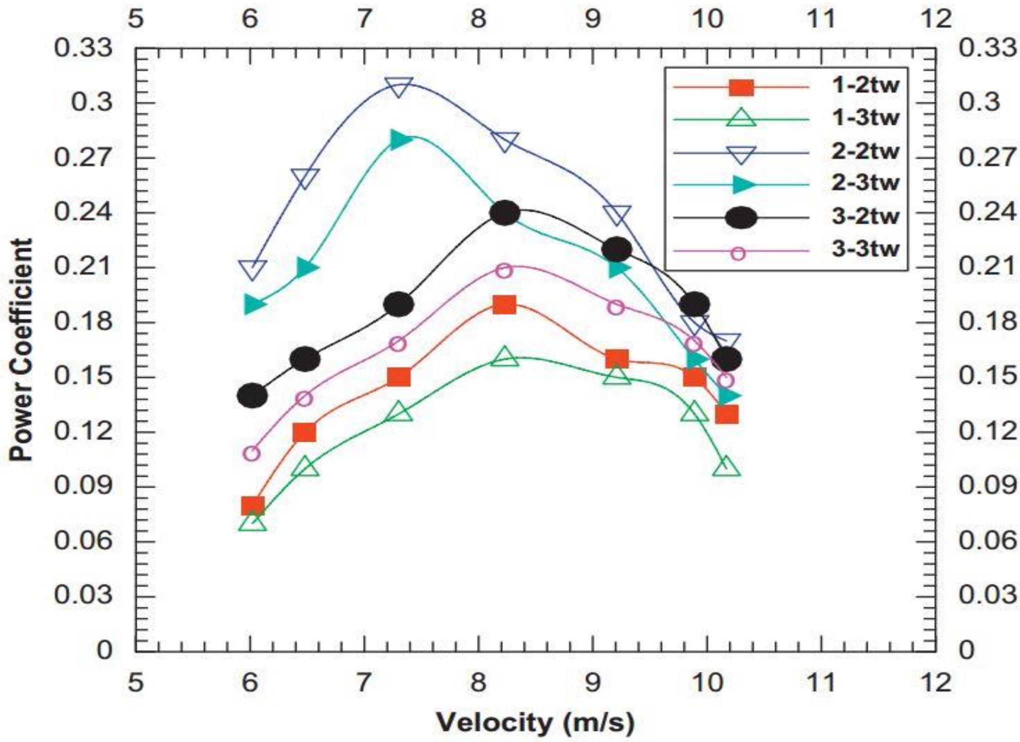


Figure 2.5 Variation of power coefficient with velocity for twisted Savonius rotor system.

By taking a Savonius turbine for 2 and 3 blades it was concluded that the power coefficient for both 2 and 3 blade savonius wind turbines as shown in the figure 2.6a,b. It appears that the power coefficient of 2-blades has a remarkable increasing value than the 3-blades. It appears that the 2-blade savonius wind turbines has its highest value of (0.21) at the tip speed ratio of (0.8), and the 3-blades has a value of (0.17) at the tip speed ratio of (0.8) [28].

(a)

(b)

Figure 2.6 a,b The power coefficient variation with the tip speed ratio for 2 and 3 blades savonius wind turbine.

Vertical axis wind turbine of Savonius based on drag, it has a high starting torque and a good performance at low tip speed rates. There are a lot of researches that have studied this type for two or three blades. Three-blade Savonius rotor with different overlay ratios was taking place.

A comparison was made between three models with different overlapping ratios, no overlap, 0.12 and 0.26 using GAMBIT and FLUENT together with a wind tunnel. The results showed that the model 0.12 has the highest torque coefficient at all wind speeds. The non-overlapping model achieves the best power coefficient at low wind speeds. [29],the following Figure 2.7 shows the overlap ratio of 0.12.

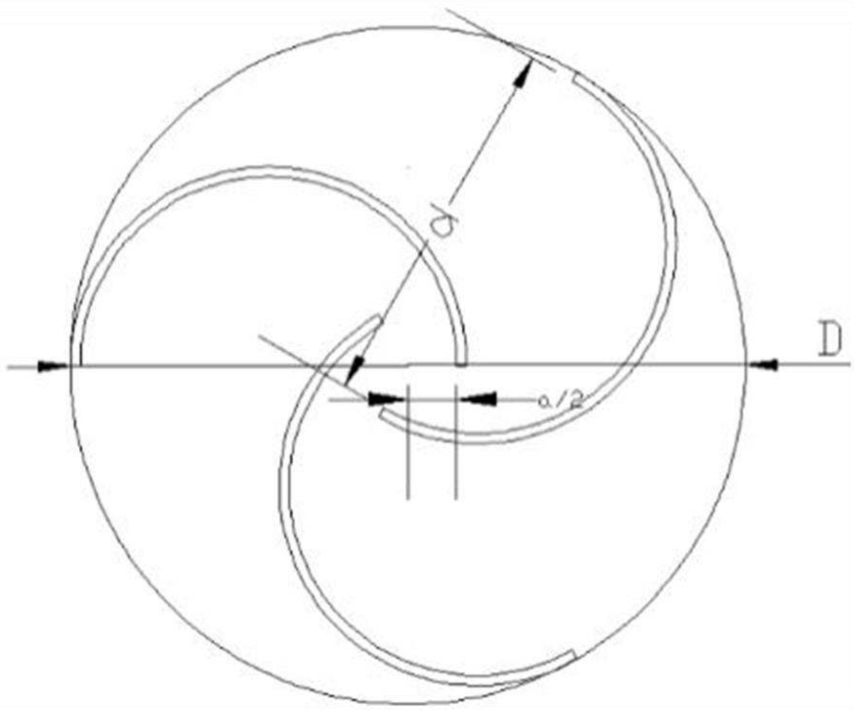


Figure 2.7 Top view of Savonius model with overlap ratio of 0.12 [29].

Two, three, and four blades were used to compare the tip speed ratio, torque and power coefficient associated with wind speed by using ANSYS 13.0 software. The results showed that the Savonius model was affected by the change in the number of blades used. The three blades Savonius model has a better performance in tip speed ratio at the highest ratio of 0.555 for wind speed 7 m / s as shown in figure 2.8. But the four-blade wind turbines have higher torque than the two blades and three-blade turbines, as well as having a performance at a lower tip speed ratio, while three blade turbines have better performance at a higher tip speed ratio [30].

A five blade turbine was studied and the coefficients of drag and torque coefficients were calculated by calculating the pressure distribution on the surface of the blades with variable rotor angles, as shown in Figure 2.9.

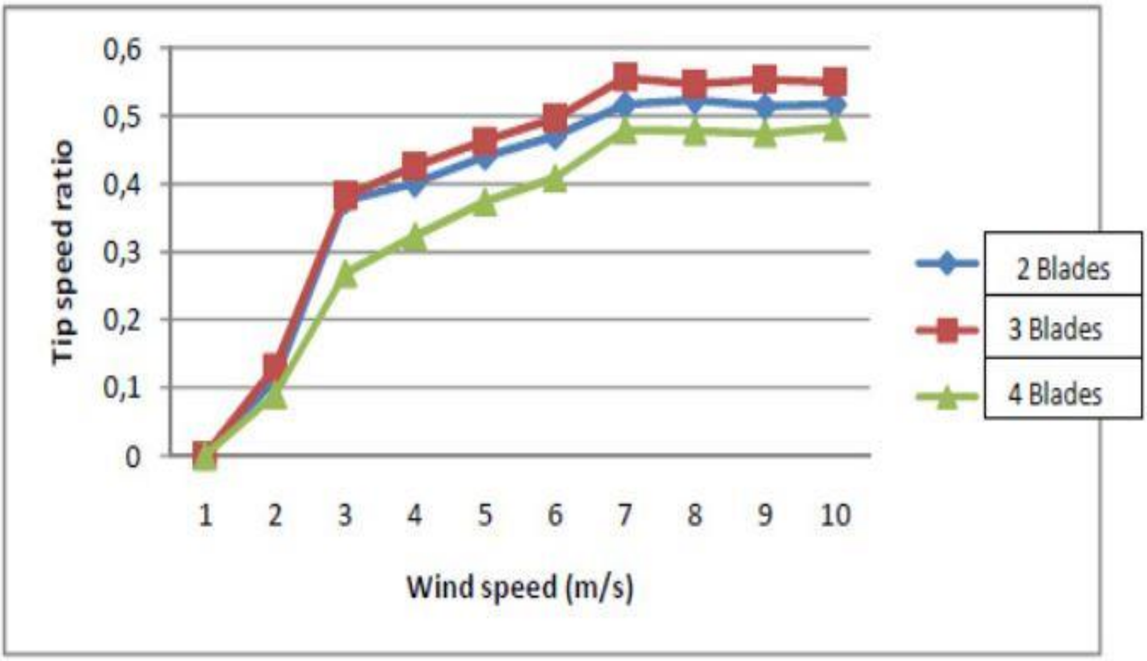


Figure 2.8 Tip speed ratio related with wind speed (m/s) in wind tunnel .

Figure 2.9 Five bladed vertical axis vane type rotor [31].

The experimental investigation has been completed at Reynolds number 1.65 × 105 in a uniform flow plane produced by an open circuit wind tunnel. It was observed that the total static torque increases from 0º to 10º and then it reaches its maximum value before it drops to 30º, total static torque increases up to 72º, as well as sum of the torque constant coefficient, the curve is repeated at the angles of the changing rotor from 72º to 144º, 144º to 216º, 216º to 288º, and 288º to 360º angles of rotation. Which contributes to the large torque output is the reflectivity between the torque coefficient and the normal drag coefficient.

By analyzing the static torque coefficients of a five-blade turbine, it was found that the total static torque changes with the variable rotor angles. Finally, it was observed that when the number of blades increases the curve of Cp vs. λ curve will be steeper, this means more power is available [31].

The power coefficient was studied taking a different values of the tip speed ratio and the torque coefficient at different values of helical blade angles of 0º, 45º, 90º and 135º under constant conditions of projection area and aspect ratio.

Using the incompressible unsteady Reynolds average Naviere Stokes (k-ε RNG), the experiment results culminated in the success of the tip speed ratio (TSRs) and the maximum power coefficient (Cp, max) values with the variable angle of torsion.

(Cp, max) at angle of torsion 45º is approximately 0.13, as well as at the other torsion angles 90º and 135º, but at the angle of torsion 0º gave different value. But in the end, the values of (Cp, max) seem rather equal. As for the torque it appears to be stable at the angle of twisting 90º but its maximum value seems to change at the angle of torsion 0º and azimuth angle 45º. As for the pressure distribution around the blades surface. The convex blade is where the pressure distribution at the maximum value while the minimum is at the concave blade. When the blades rotate, some of the sections gets obstructed by the effective torque while others are obstructed by the effective drag force [32].

Using a wind turbine model of a diameter and height of 32 cm containing a shaft is connected to an electric generator (DC), with double wind tunnels to detect the effects of wind speed and wind angles on the possibility of voltage generating from the Savonius wind turbines. The results showed that high levels of voltage generating were produced between 23.2º and 35.5º and the 30º angle provided the highest possible voltages from wind angles 0º to 90º. As a conclusion, the wind turbines generated peak voltages between 7.28 to 11.28 volts at a wind speed between 4.86 to 6.41 m/s as shown in figure 2.10 [33].

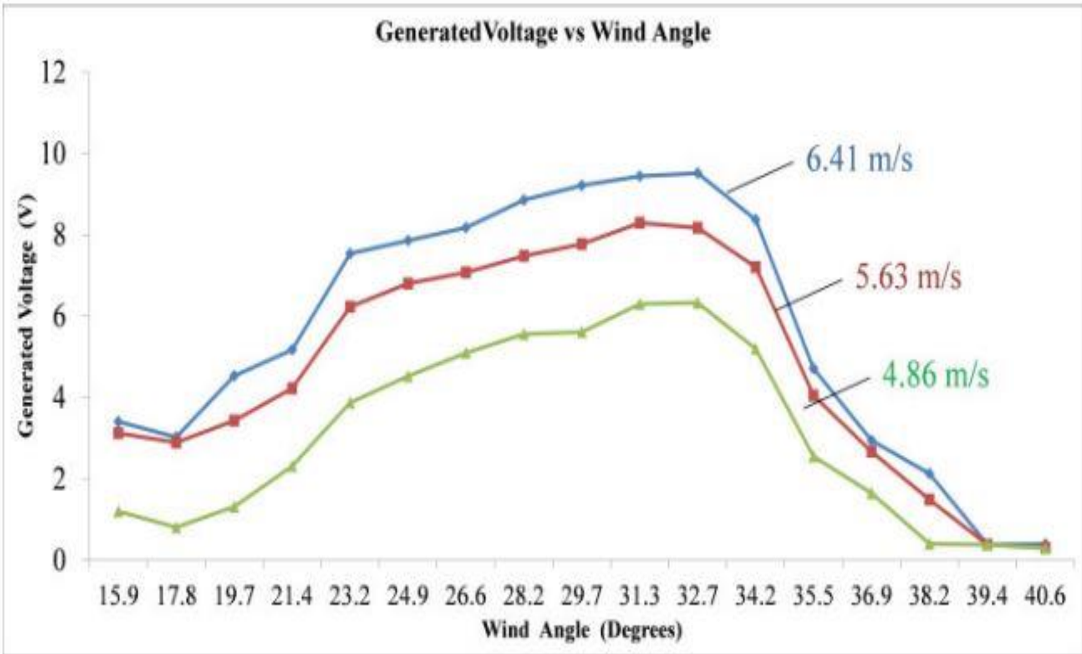


Figure 2.10 Generated voltage of the proposed wind turbine at different wind angles.

Other factors that lead to more efficient turbines are the improvement in designs, to find out which design is more efficient, five models of three-bladed Savanuios designs have been studied, three of which are innovative, various simple airfoils and experimentally tested by placing it against a wind tunnel with simulation software FLUENT. Torque, lift, drag, pressure and power coefficients were measured at three different speeds then it was compared.

The results showed that NACA7510 provides better torque coefficients than all other models and that the power coefficient gives a similar ratio to the torque coefficients and higher TSR gives a better power coefficient for all models. NACA7510 presents the best power coefficient, on the other hand as a computationally matter, the turbines with a quarter-circular blade and a NACA 9510 gives the best power coefficient. when wind speeds increase, the force of drag increases.

As a computationally matter, NACA5510 gives the highest drag coefficient. But for NACA7510 it gives the highest lifting coefficient at TSR 0.301, as shown in figure 2.11 [34].

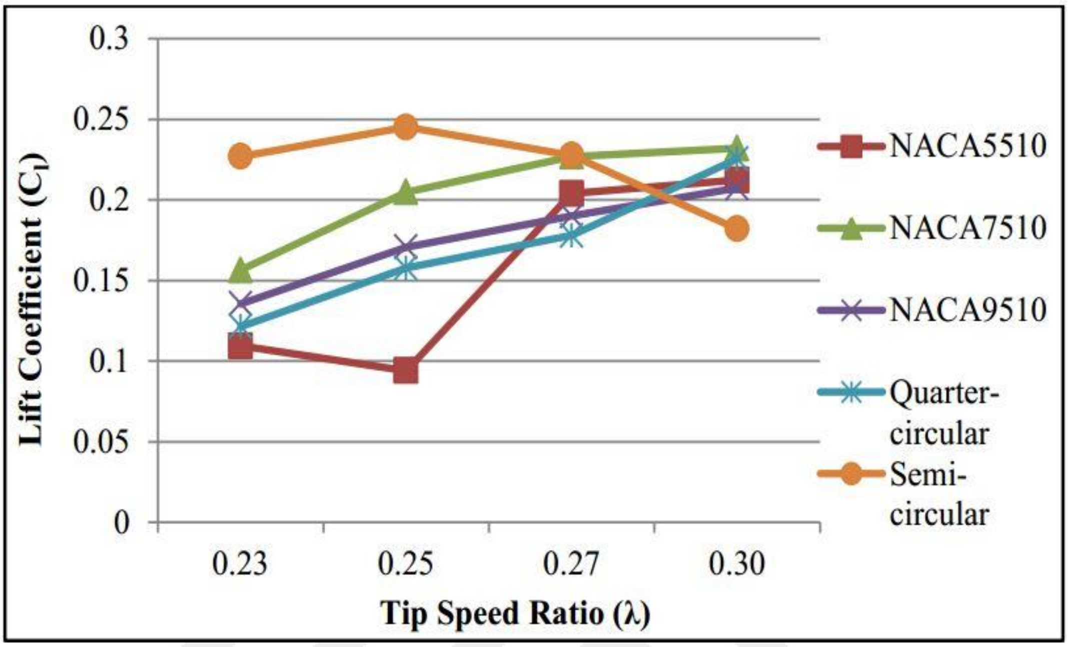


Figure 2.11 Average Lift Coefficient (C l) vs. Tip Speed Ratio (λ) for Different Blades.

The general characteristics of the Savonius rotor were studied through different overlay ratios. Based on power coefficient and torque coefficient, the performance of this rotor was assessed.

The results showed that the ratio of internal overlaps has a clear effect on the efficiency of the rotor. Both the power coefficient and the torque coefficient are at optimal values when the internal overlap ratio is 0. When the value of the internal overlay increases, the power values are reduced at the same speed λ [35].

A variable rotor with two or three or four blades was studied, with single steps and double steps, with end plates and without end plates, and overlapping ratios from 0 to 0.35 with side ratios of 0.5, 1, 2, 4 and 5.

All of these elements are experimentally tested to find the optimal designs of the Savonius turbines. The results showed that the two-blade rotor is more efficient than the three-and-four blades as shown in figure 2.12, as well as double steps have better performance than single steps. The rotors with the end plate gave better efficiency than the rotor with no end plates. The rotors without the overlay ratio are better than rotors that have an overlay. The power factor also increases with at the highest aspect ratio (α) [36].

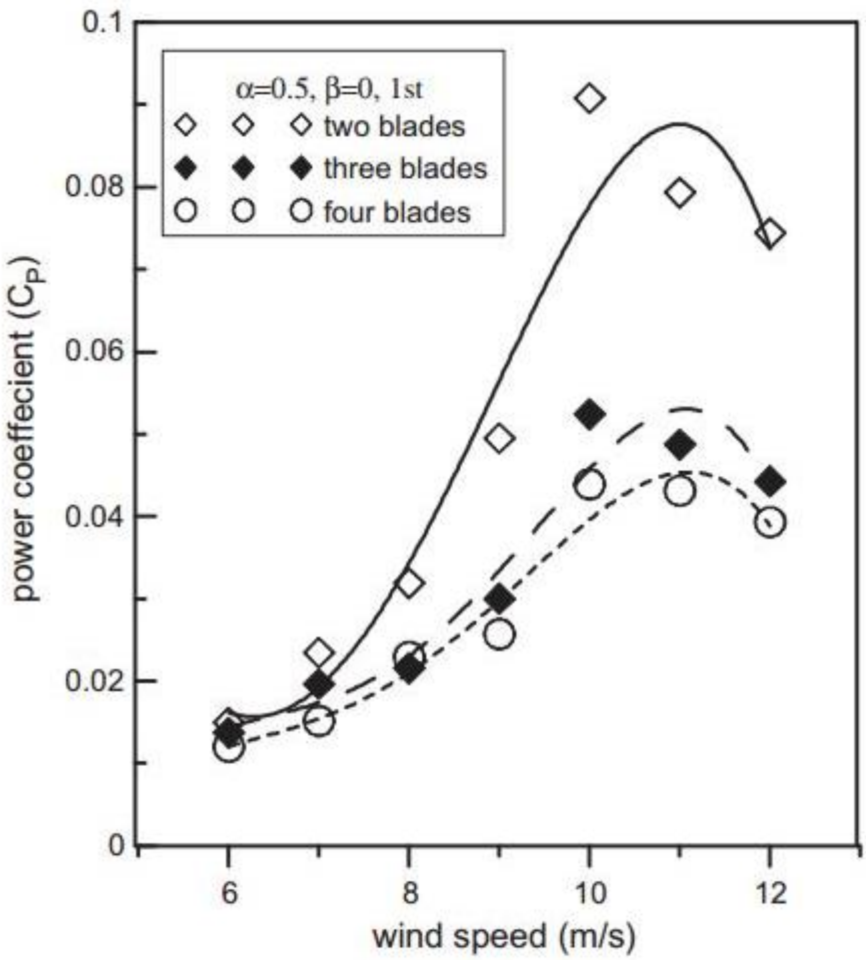


Figure 2.12 Relation between power coefficient and wind speed for rotors with two, three and four blades.

Two different forms of the Savonius rotor were studied, semicircular and a part of the circle shape to find out which configuration will have better performance than the other. Using the Solidworks CFD software, the static torque coefficients were compared at different overlap ratios 0%, 20%, and 40% for both types. The flow around the rotor was also analyzed with at different overlay ratios with the help of speed.

The results showed that the torque coefficient and the velocity distribution at the angle of attack could be at the maximum at overlap ratio of 20% for both types, therefore; the overlay condition 20% is the best overlap in the rotor performance, as well as the rotor made from of a part of circle shape is giving the maximum torque coefficient. As for the variable velocity value, it gives the peak value at attack angle of 30º and 120º, this means that these angles make the rotor at its best for the power extraction [37].

The journey to improve the performance of Savonius turbines continues in various studies. Modifications have been made to the Savonius rotor blades, it was a combination of combining the traditional form known as a circle with another blade of a concave elliptical, as shown in the following Figure 2.13.

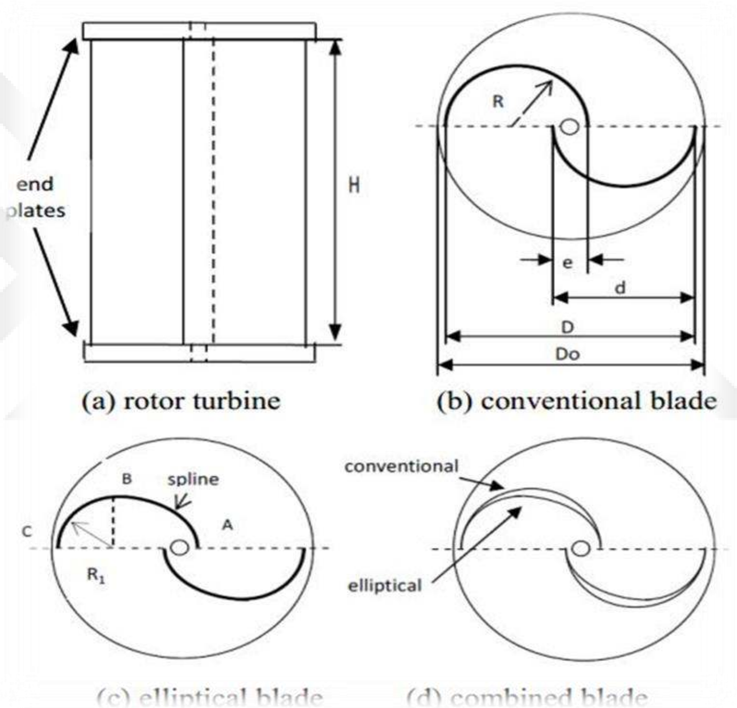


Figure 2.13 combination of combining between the traditional and concave elliptical [38].

On the condition of this structure does not affect the method of building simple Savonius turbines and the cheap cost of making it. The results obtained from this study that this blade improved the performance of the maximum power coefficients (Cp,max) up to 11% compared to the traditional blade and 5.5% compared with the elliptical blade at a tip speed ratio of 0.19. The power coefficients and torque coefficients are more stable along the speed ratios of the tip compared to the performance of the traditional blades [38].

2.4. Literature review on Darrieus Rotor

The Darrieus turbine is similar to the H-rotor turbine in terms of the vertical axis as well as the working mechanism on the basis of the lifting forces placed on the blades. The big difference is in how the blades are connected to the shaft.

The blades are attached to the shaft at each end of the blade because the Darrieus turbine is shaped as an egg beater, as shown in Figure 2.14.

The bending in the blades lead to supporting the vertical shaft by a number of wires. This means that the main tower does not have to be as solid and strong as in the H-rotor, as for the defects in Darrieus's turbine, it does not have a good starting torque. This means that it cannot rotate easily in low wind speeds. [39].

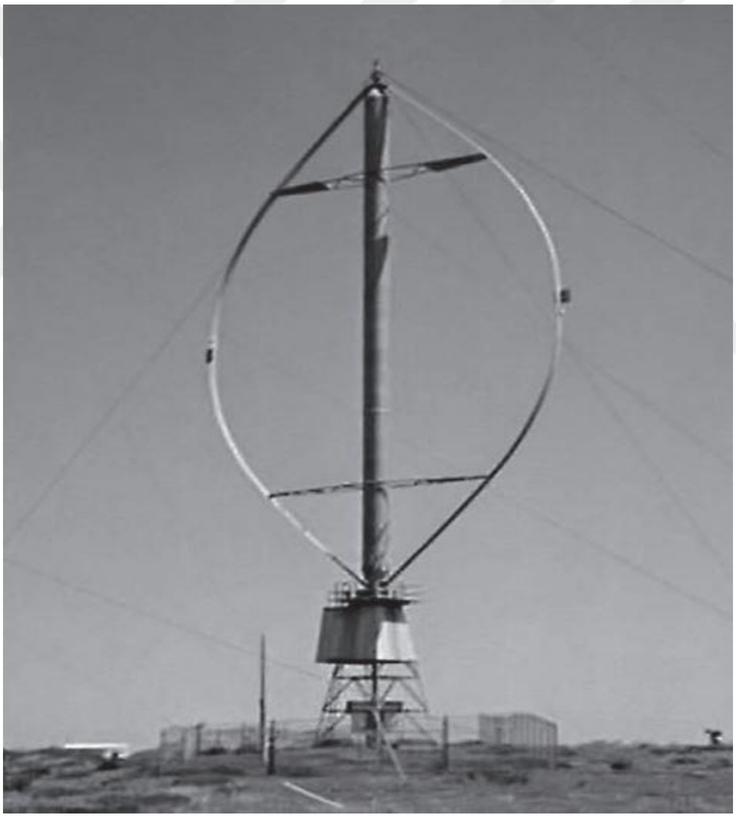


Figure 2.14 Darrieus turbine. [39]

For Savonius rotor, there have been many experiments that have been studied in order to find the best performance of Darrieus rotor. Among these investigations are numerical studies and simulations in the wind tunnel as well as in the field, through these investigations, the aerodynamic characteristics and the effects of the design of the blade and the angle can be identified, including the material made from and its composition.

The self-starting property of the Savonius rotor is better than the Darrieus rotor. This is why it considered one of the most difficult characteristics to be studied with Darrieus. Numerical simulations of different rotational speeds were performed to determine the torque resulting from each rotation speed.

Based on the aerodynamic and mechanical forces that operates on the turbines. This simulation starts from the first case, in which Darrieus is at a constant movement to its final state, which is the state of continuous rotary rotation. The results showed that the presence of vortices in the initial state of the turbine reduces the start of torque causing the generation of a low initial turbine acceleration, but when TSR is more than 1.0, the blade swirls decrease, the blades also generate high lift force leading to a better turbine acceleration. As for the inertia, it is an effective factor in the performance of the turbine in terms of aerodynamics, it makes the rotor more rigid, which leads to taking great time for the rotor to reach the final speed required [40].

In this study the difference in the performance of the turbine was compared with the area affected and with the rigidity of the rotor through the analyzing of aerodynamics. A comparison was also made in terms of changing the number of blades to two or three blades and hand loads and other factors. As it's well known that the three-blade rotor has better performance than the two-blade rotor. It can also be noticed an increase in the rotor performance at the beginning of TSR through the calculations that were made using the DU 06-W-200 cambered airfoil as shown in figure 2.15 [41].

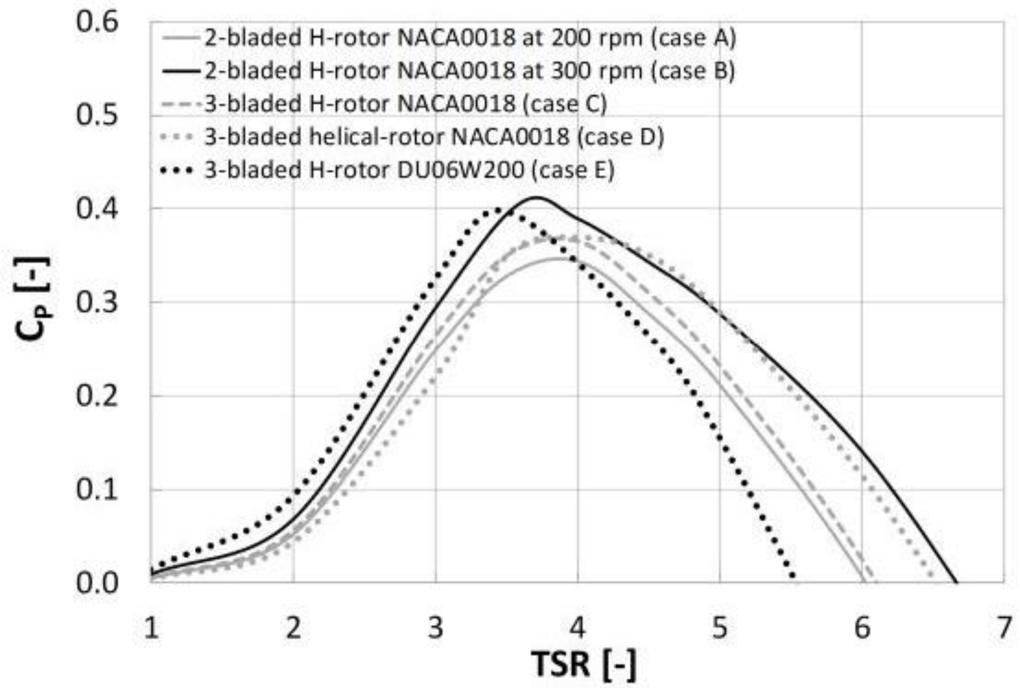


Figure 2.15 Power coefficient CP curves at different TSRs.

Turbine design has an effective role in influencing wind turbine performance, through the use of Double Multiple Stream Tube. The focus was on how the Reynolds number of rotor blade affected the performance of the turbine through numerical analysis. Also it consider the general design of the specifications of different turbines through the analysis of dimensions.

The results of this work showed that the higher the wind speed the lower the tip speed ratio of the maximum average of power coefficient. The higher the rotor stiffness the higher the maximum power coefficient value and the lower the negative power coefficient value at the lowest tip speed ratio, as shown in figure 2.16 [42].

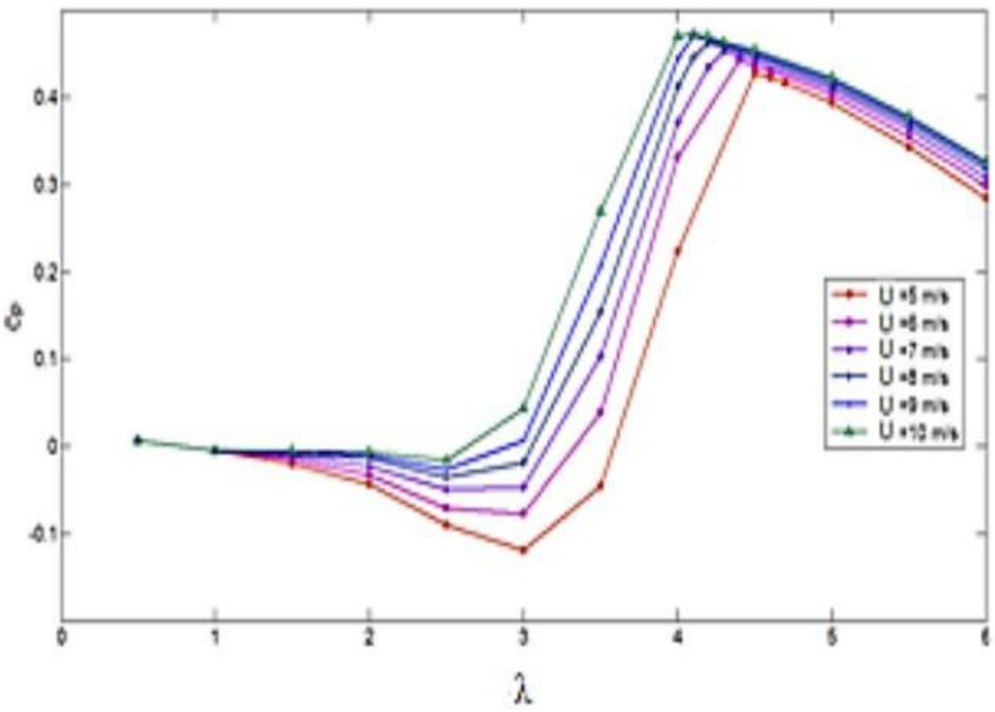


Figure 2.16 Relation between tip speed ratio λ and power coefficient Cp for different inlet wind speed.

CHAPTER 3

METHODOLOGY

3.1. Introduction

In this part of the thesis, the aerodynamic characteristics of the vertical axis wind turbine Savonius (VAWTs) are examined with different number of blades by using the experimental method. The experimental work is performed under the normal weather conditions of Gaziantep for pressure, temperature and wind speed to determine the coefficients of the aerodynamics which includes power coefficients and torque coefficients. Precisely, this chapter talks about how to conduct experimental data results for the turbine. To obtain the data a turbine is designed and manufactured containing five and two blades, also this chapter contain the method of generating electricity by connecting a simple circuit with the turbine.

3.2. Turbine

The vertical axis wind turbine (VAWT) is one of wind turbines that is used to turn the wind energy to mechanical energy and then converting this mechanical energy into electrical energy by connecting a generator to the turbine rotor that leads to abandon the energy produced by the fossil fuels with reducing environmental disadvantages resulting from using fossil energy. As mentioned in previous chapters, vertical wind turbines do not depend on the direction of the wind, furthermore, it is known for its easy design, cheap cost and without the need of elevated places because it's operating well at low grounds, even in low winds, therefore; it's suitable for urban areas, on the other hand it is considered a low energy producing comparing with their eternal traditional competitor horizontal axis wind turbine type (HAWT).

The turbine Savonius used in this experimental work is made using a barrel for two models:

- **Model one**: An empty oil barrel of 58 cm diameter was used in this study, five openings were made on the sides of the barrel working as blades, the blades were bent with an equal angles of (72º), the length of turbine is 77.5 cm, the radius is 42 cm, the overall diameter 84 cm and the thickness is 1.33 mm, as shown in Figure 3.1.

Figure 3.1 The model one of turbine Savonius.

- **Model two**: Take the barrel again and cut it into two halves to get two blades at equal angles 180º, the radius of turbine is 51 cm, height 77.5 cm, the overall diameter rotor 102 cm and the thickness is 1.33 mm, as shown in Figure 3.2

Figure 3.2 The model two of turbine Savonius.

The Savonius turbine in this research for two models consists of two main systems as follows:

3.2.1. Mechanical system: is consisting of several parts, their main function is to convert wind energy to mechanical energy, the mechanical parts will be discussed in details as follows below:

- To both it a pulley of 58 cm diameter was placed at the bottom of the barrel to be in a straight line with the pulley attached at the alternator, also a (V-shaped) belt was used to connect between the two mentioned pulleys, this belt shall be the link between the mechanical and the electrical systems, as shown in Figure 3.3.

Figure 3.3 Barrel combined with the pulley.

- A steel shaft of 7 cm diameter was used to support the turbine, the shaft length is 290 cm with also considered as the turbine height. The turbine's barrel was placed on the upper part and the lower end of the shaft was fixed to a cylindrical base. A circular steel base of a diameter of 100 cm was used to support the turbine, the heavy weight of the steel base helped to maintain the turbine balance, also it gave the turbine more safety against the axial movement. Also additional weight was placed on the circular base to give more stability, as shown in Figure 3.4.

Figure 3.4 Turbine base with additional weight.

3.2.2. Electrical system: is consisting of several parts, their main function is to convert the mechanical energy to electrical energy, the electrical parts will be discussed in details as follows below:

- **Generator**: In order to convert the mechanical energy that generates from the wind turbine rotation to electrical energy, a generator connected to the rotor shaft. The generator used in this study can generate DC and AC electricity. It's better to use the DC machines with small applications and an AC machine with large applications. The important thing for wind turbine applications is the right choice for an electric generator that suitable for needs. Factors to consider in choosing the generator are the source and type of load and the speed of the wind turbine. A washing machine motor with a (1500 RPM/min, 50 Hz), modifications were made to convert it to a permanent magnetic generator consisting of 2 and 4 Neodymium magnet, and also a pulley of 5 cm diameter was attached to the generator, as shown in Figure 3.5. Such generators don't need a gear-box which is blamable for noise and maintenance, so permanent generators are more efficient and reliable than induction generators. That's the most important reason why they are used in small applications.

Figure 3.5 Permanent magnetic generator.

This generator has multiple electrodes, which allows to connect easily with the rotor shaft, these generators are very popular because of its low cost.

- A diode bridge between the battery and the generator was used transfer the energy to the storage battery, also to convert the energy to direct current, electricity has been produced from low revolutions, and light as alternating current is provided to incinerate. Because of light illuminated intermittently, alternating current is converted to direct current, as shown in Figure 3.6.

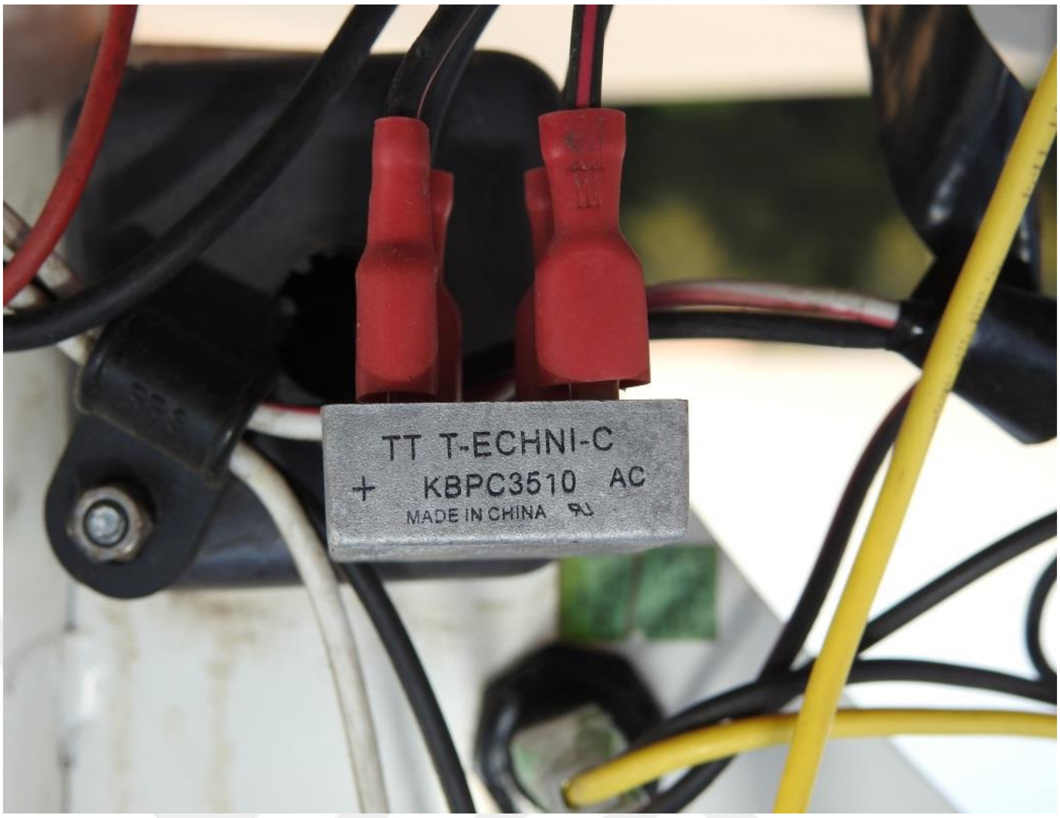


Figure 3.6 the diode bridge.

- The voltage regulator is connected to cut the energy to prevent the battery from extra charging that might lead to an explosion, as shown in Figure 3.7.

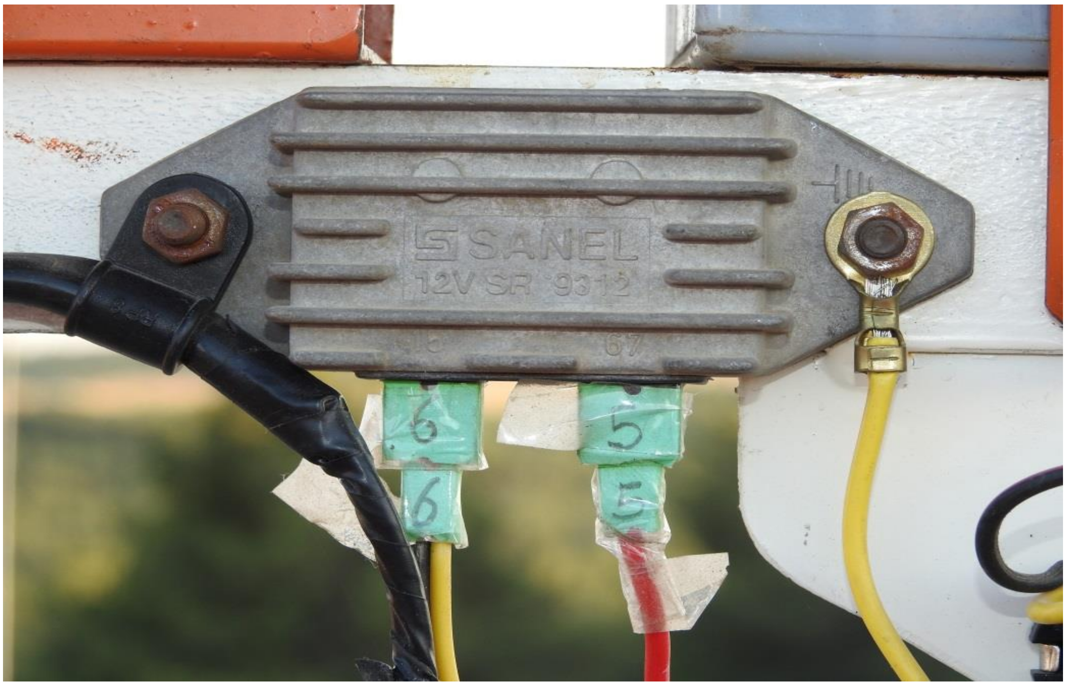


Figure 3.7 The voltage regulator.

3.3. Test Set-up

After searching for a suitable place inside the Gaziantep university perimeters, the suggestion was set on placing the turbine on the roof of Seyirtepe Restaurant, which located on the higher position in the university territories. The roof of the restaurant was well known of the obstacles emptiness in four directions which helped in obtaining wind current perfectly from all directions.

After choosing the suitable place, the turbine was moved from the physics laboratory- Gaziantep University to the restaurant roof as shown in Figure 3.8.

Figure 3.8 Turbine location.

The experimental work started in first June for 5 blades model and on the first of July for the 2 blades model, collecting data lasted for 12 hrs from 10 am to 10 pm for each work day, the data recorded every 5 min for wind speed, rotation speed, voltage, electric current, atmospheric pressure and temperature.

3.3.1. Wind velocity device

The wind velocity was measured by holding Anemometer by hand, for measuring the wind speed the device was placed on the opposite side of the wind direction by holding it vertically. Also, it gives the speed in m/sec unites, as shown in Figure 3.9.

Figure 3.9 Anemometer device.

The wind direction was indicated by using a wind vane to know from where the wind is blowing as shown in Figure 3.10.

Figure 3.10 Wind vane.

The anemometer has the ability to air volume in different residential types, also it measures maximum or the average wind velocity. The measuring range is from 0.2 to 30 m/sec by $\pm$ 0.1 m/sec accuracy.

3.3.2. Rotational speed device

The speed rotation device also known by the scientific name Tachometer digital was used to calculate rotation speed for various wind velocities, as shown in Figure 3.11.

Figure 3.11 Tachometer digital device.

The reflective tape was place on the turbine's bottom to reflect the infrared ray during the rotation, therefore; it enables the Tachometer digital to receive the reflected light for the mentioned tape to show the various changes in the frequencies, through these changes with taking in consideration the time passage it gives us the wind turbine rotation speed.

The power generation system is placed beside the turbine transmission shaft, it contains the power generator**,** diode bridge, voltage regulator and resistive load. DC current is generated by using this system type to operate the LED for lighting. A simple circuit was connected directly with the generator consists of (5) watt lamp to measure the AC current and voltage by using a multimeter as shown in Figure 3.12.

(a)

(b)

Figure 3.12 Multimeter devices (a) for measuring electrical current and (b) for measuring the voltage.

3.4. Mathematical Expressions

Through the calculation of the data for the two models in this work it is necessary to perform the analysis to compare the performance of the models with the other studies. Non-dimensional coefficients are used for comparison to other similar study and authentication of the experiment. Two of these universally used non-dimensional objects are considered for this study. The power coefficient represents the energy conversion efficiency of the turbines as well as the tip speed ratio represents the ratio of the blade tip speed to the free stream wind speed [43]

Through the equations to be listed below, we can calculate the power coefficient and find the value of the tip speed ratio across a set of different wind speed for each rotary design with two blades and five blades

The swept area of a wind turbine can get it from the dimensions of the rotor, as shown in Figure 3.13.

$$\mathbf{A = H.D} \qquad \mathbf{(1)}$$

Where A The swept area, H is rotor height (m) and D the rotor diameter (m).

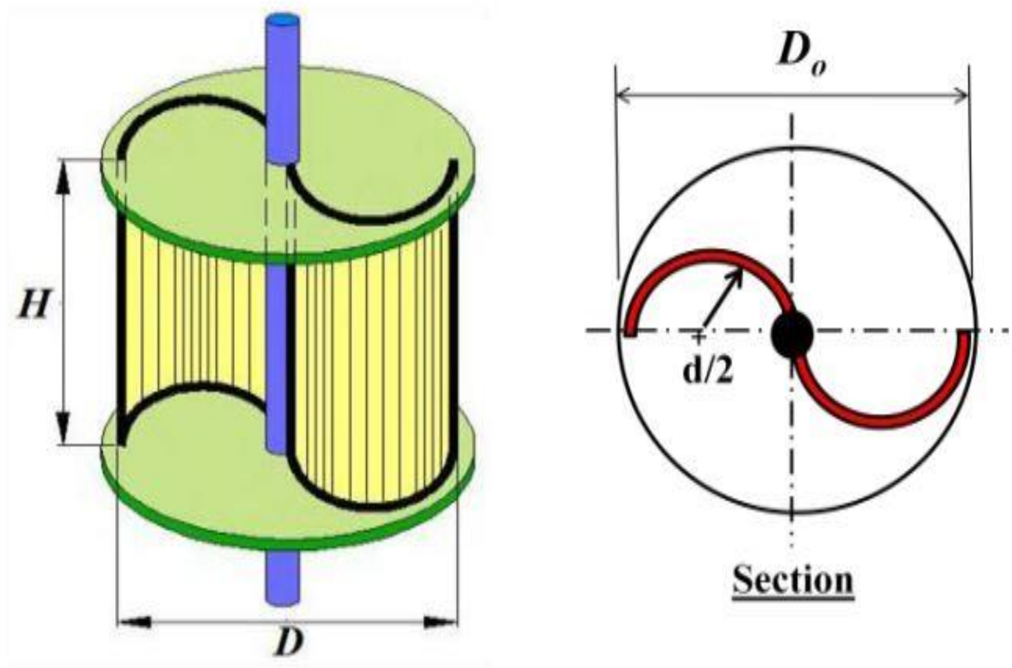


Figure 3.13 Schematic diagram of rotor wind turbine. [28]

The actual available power from the wind is:

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

Where ρ air density (kg/m^3) And $\boldsymbol{v}$ wind speeds (m/s).

The electrical power produced from the generator is:

$$P_e = I.V \qquad (3)$$

Where I electric current and V voltage.

The power coefficient (Cp) is assumed by

$$C_p = \frac{P_e}{P_a} \qquad (4)$$

The angular velocity of the rotor is:

$$\omega = \frac{2\pi N}{60} \qquad (5)$$

Where $\boldsymbol{\omega}$ angular velocity ($^{rad}/_{sec}$), $\boldsymbol{N}$ rotational speed (RPM).

The tip speed ratio ($\boldsymbol{\lambda}$) given by:

$$\lambda = \frac{\omega d}{v} \qquad (6)$$

Where $\boldsymbol{d}$ is the diameter of the blade (m).

CHAPTER 4

RUSELT AND DISCUTION

4.1. General

The main variables of the vertical wind turbine made of barrels are the power coefficient and the tip speed ratio. This work included two models, the first model contains on five blades, the second model has two blades, and the performance difference between it by analyzing these values calculated under the natural conditions of the weather situation for the Turkish city of Gaziantep.

In addition to finding whichever is better for the generation of electricity with the change of wind speed and stay same as the use of load on the generator.

4.2. Performance Results

The efficiency of wind turbines is characterized by a parameter known as the coefficient of performance, or Cp. This coefficient ranges from 0 to 0.59. The numerical value 0.59, or 16/27, is the Betz limit, which representation is the maximum theoretical efficiency that any wind turbine removing energy from a fluid can achieve. The Cp coefficient of a turbine is determined primarily by the aerodynamic forces, which are affected by the shape of the blades.

The forces experienced by the blades will vary depending on the wind flow conditions, namely the relative velocity of the blade of the wind, or tip speed ratio. As the tip speed ratio is varied, the rotor efficiency will change, since the blades cannot be optimized for every tip speed ratio. The curve produced by graphing the power coefficient (Cp) vs. tip speed ratio (λ) is known as the characteristic curve of the turbine. It displays the turbine's ability to operate throughout a range of conditions. The inability of VAWTs to achieve a tip speed ratio of much greater than 1 make them unable to achieve the high Cp exhibited by HAWTs, which have proven an almost 50% efficient. Typical values for VAWTs lie within the range between 0.1 and 0.18 [44].

Current developments in blade profiling and other methods are allowing vertical machines to incorporate larger lift forces, thereby increasing their performance.

Table 4.1 Values for five blade rotor.

ϑ (m/s)	**RPM**	**V (volt)**	**I (Amp)**	**ω (rad/s)**	**TSR**	**Electric power (W)**	**Wind power (W)**	C_p
2	20	2	0.025	2.093	0.439	0.05	3.1899	0.0156
2.5	25.5	2.6	0.04	2.669	0.448	0.104	6.2302	0.0166
3	31	3.1	0.06	3.244	0.454	0.186	10.765	0.0172
3.5	37.5	4.5	0.07	3.925	0.471	0.315	17.095	0.0184
4	43	5.5	0.09	4.5	0.4725	0.495	25.519	0.0193
4.5	49.9	6.5	0.1	5.222	0.487	0.65	36.334	0.0178
5	56.5	7	0.11	5.913	0.496	0.77	49.842	0.0154
5.5	63.5	7.5	0.12	6.646	0.507	0.9	66.339	0.0135
6	70.5	8.1	0.13	7.379	0.516	1.053	86.127	0.0122
6.5	77.5	8.6	0.14	8.111	0.524	1.204	109.503	0.0109
7	84.2	9	0.15	8.812	0.528	1.35	136.766	0.0098
7.5	92	9.4	0.155	9.629	0.539	1.45	168.217	0.0086
8	100	9.8	0.16	10.466	0.549	1.568	204.153	0.0076
8.5	107.5	10	0.165	11.251	0.555	1.65	244.874	0.0067
9	117	10.5	0.17	12.246	0.571	1.785	290.679	0.0061
9.5	124.2	10.8	0.18	12.999	0.574	1.944	341.867	0.0056
10	132.5	11.3	0.19	13.868	0.582	2.147	398.737	0.0053
10.5	140	11.8	0.2	14.653	0.586	2.36	461.588	0.0051

Table 4.2 Values for two blade rotor.

ϑ (m/s)	RPM	V(volt)	I (Amp)	ω (rad/s)	TSR	Electric power (W)	Wind power (W)	C_p
2	20	2	0.025	2.093	0.533	0.05	3.871	0.0129
2.5	25.7	2.6	0.04	2.689	0.548	0.104	7.56	0.0137
3	31.5	3.2	0.06	3.297	0.56	0.192	13.064	0.0146
3.5	37	4.8	0.08	3.872	0.564	0.416	20.746	0.02
4	43.2	5.8	0.09	4.521	0.576	0.522	30.968	0.0168
4.5	49.4	6.4	0.1	5.17	0.585	0.64	44.093	0.0145
5	56	7	0.11	5.861	0.597	0.77	60.484	0.0127
5.5	63	7.5	0.12	6.594	0.611	0.9	80.504	0.0111
6	70.7	8.1	0.13	7.4	0.629	1.053	104.517	0.01
6.5	81	8.7	0.144	8.478	0.665	1.25	132.884	0.0094
7	91	9.3	0.154	9.524	0.693	1.43	165.969	0.0086
7.5	98	9.8	0.159	10.257	0.697	1.55	204.134	0.0075
8	105.6	10	0.164	11.06	0.705	1.64	247.744	0.0064
8.5	114	10.36	0.169	11.932	0.715	1.75	297.159	0.0058
9	123	10.75	0.178	12.874	0.729	1.91	352.744	0.0054
9.5	131.1	11.2	0.189	13.72	0.736	2.115	414.862	0.005
10	140	11.8	0.2	14.65	0.747	2.36	483.875	0.0048
10.5	150	12.8	0.22	15.7	0.762	2.816	560.145	0.005

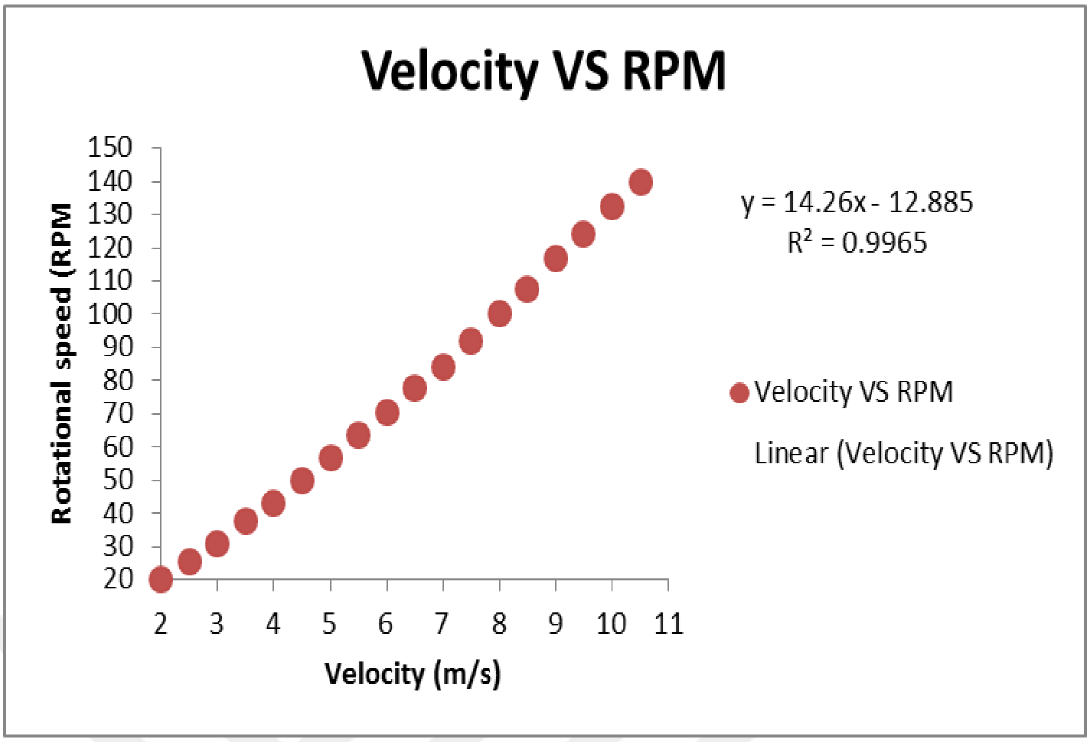


Figure 4.1a Relation between velocity and rotation speed of five blade rotor.

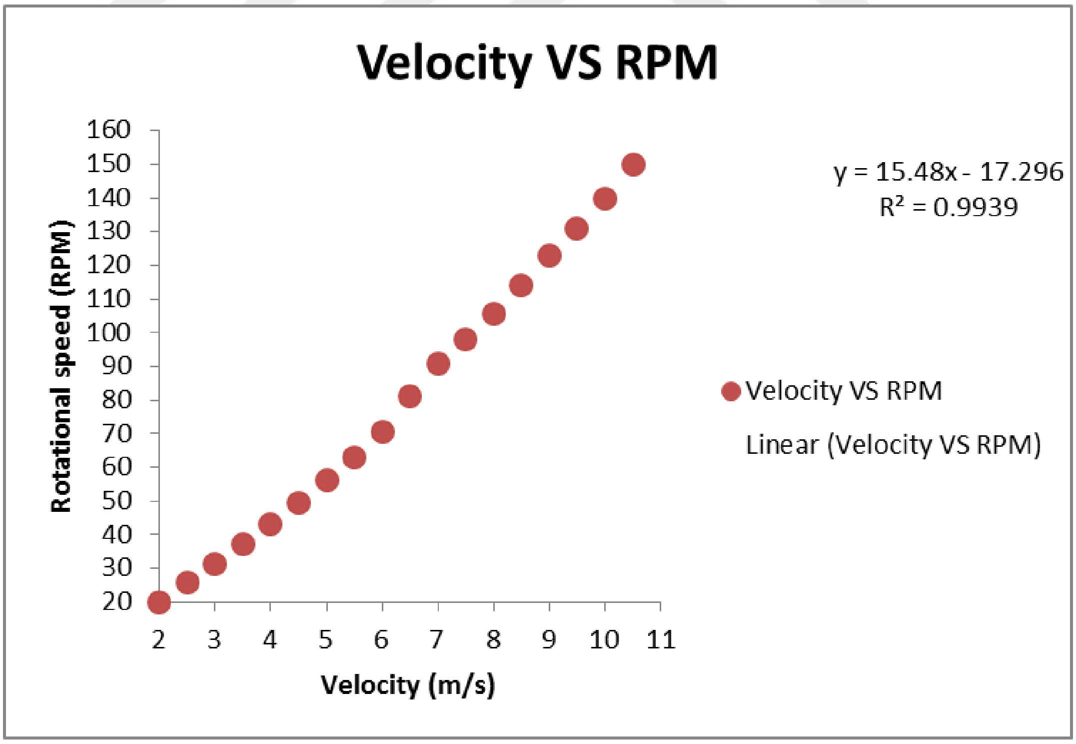


Figure 4.1b Relation between velocity and rotation speed of two blade rotor.

From the graph as shown in figures 4.1a and 4.1b display the relationship between the speed of rotation and wind speed ranging from(0 to 10.5) m/s for both models. Note that both models have the same the best self-starting 20 RPM at 2 m/s wind velocity, but the graph shows that the two-blade model has the highest rotational value of 150 RPM while the five blades up to 140 RPM (see Table 4.1 and Table 4.2). This is due to the increase in the number of blades leads to an increase in the number of convex surfaces that negatively affect the strength of clouds, which leads to the disruption of the speed of circulation and this affects the actual performance of the turbine.

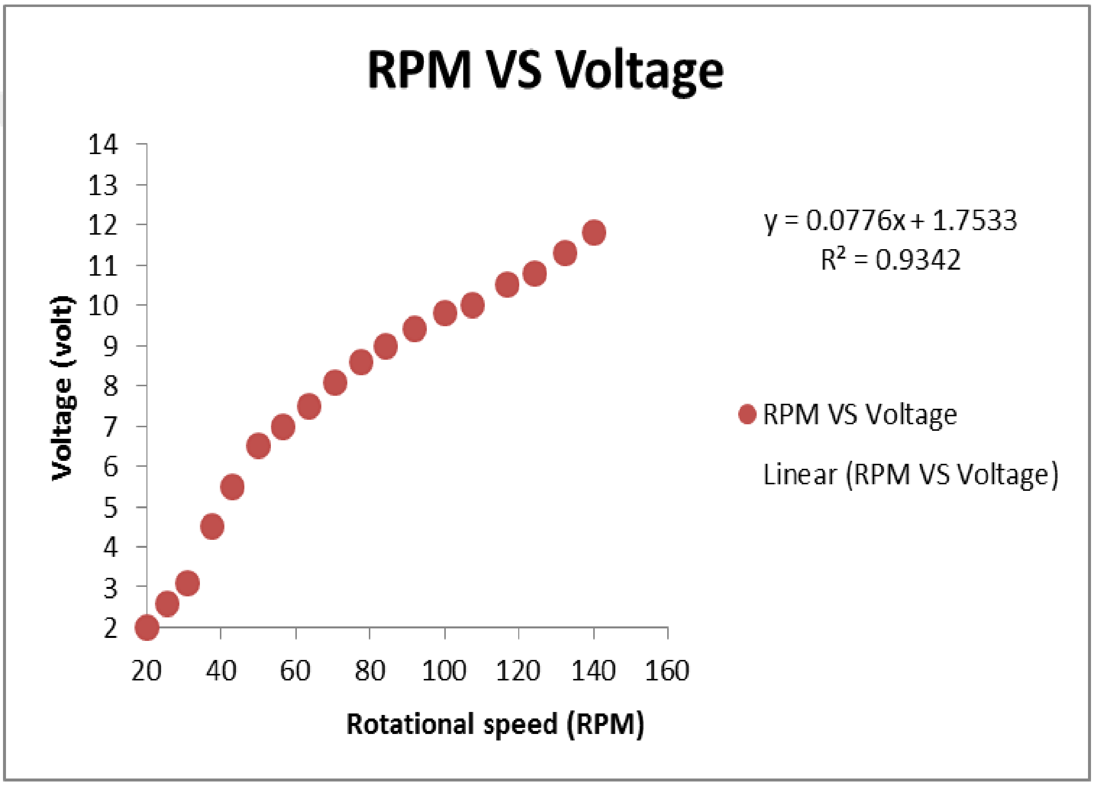


Figure 4.2a Relation between rotational speed and voltage of five blade rotor

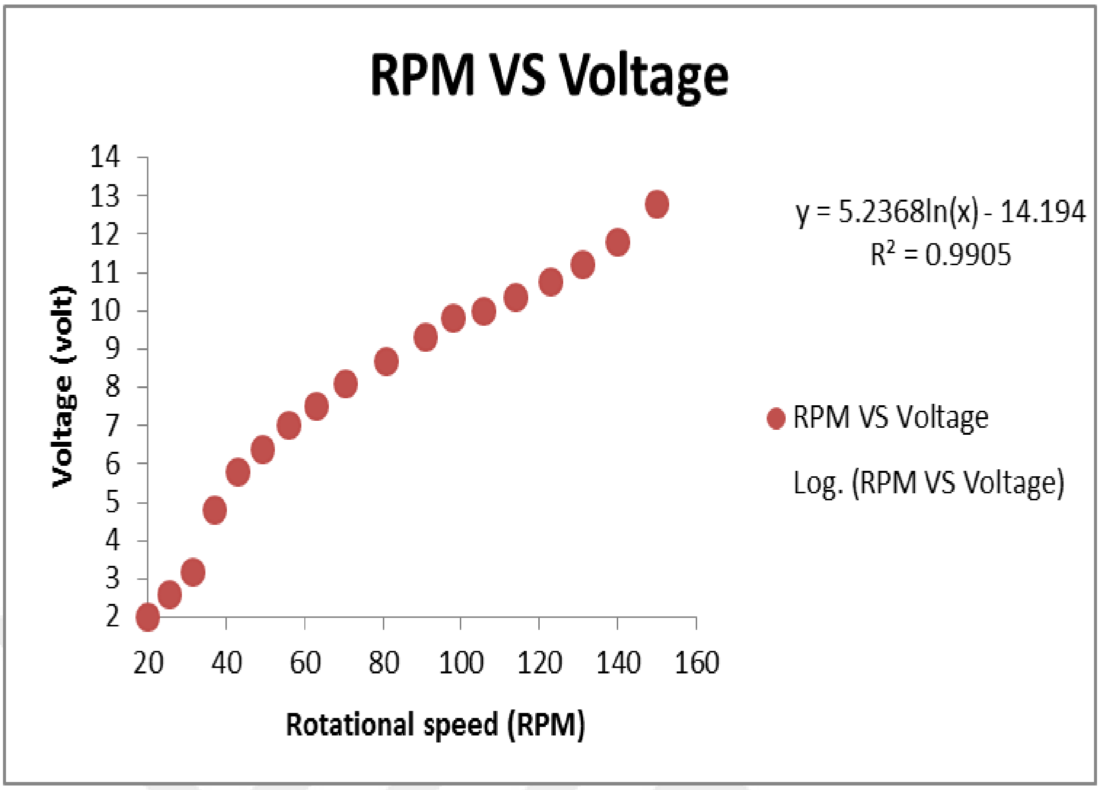


Figure 4.2b Relation between rotational speed and voltage of two blade rotor

Through the graph showing the relationship between the speed of rotation and the voltage to both models as shown in figures 4.2a and 4.2b. Note that the highest value of the rotational speed of 150 RPM for the two-blade model generated (12.8 volts), while the five-blade model at the highest speed of rotation 140 RPM generates (11.8 volts), at the same wind speed 10.5 m/s (see Table 4.1 and Table 4.2). This is because the ability of the two-blade model to rotate more than five blades leading to an increase in the number of generator cycles responsible for generating this voltage.

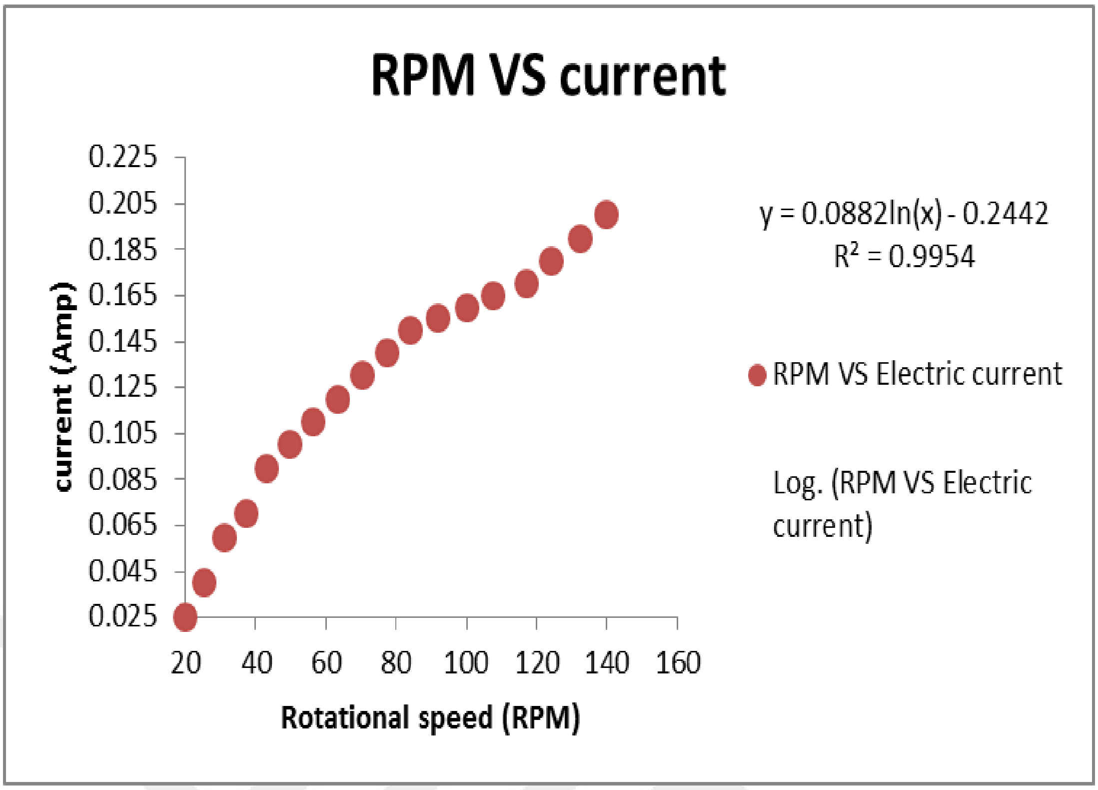


Figure 4.3a Relation between rotational speed and current of five blade rotor.

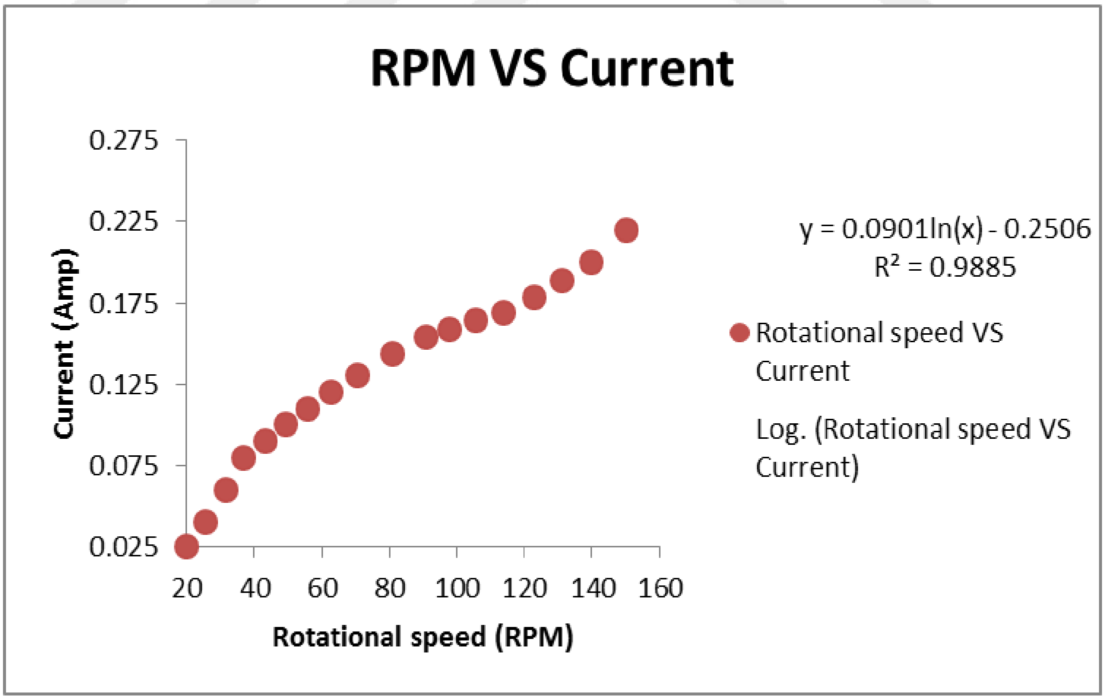


Figure 4.3b Relation between rotational speed and current of two blade rotor.

The figures 4.3a and 4.3b clarify the relationship between the rotational speed of the rotor and the current generated by connecting an electric lamp with the alternator by a leading- in wires. That the possibility of two-blade rotor to rotate more than its counterpart gives it the preference to generate a larger current up to (0.22 Amp) while the five-blade rotor up to (0.20 Amp) (see Table 4.1 and Table 4.2). It seems this give preference to making a rotor with fewer blades and making it easier to cut the barrel into only two halves rather than five equal parts.

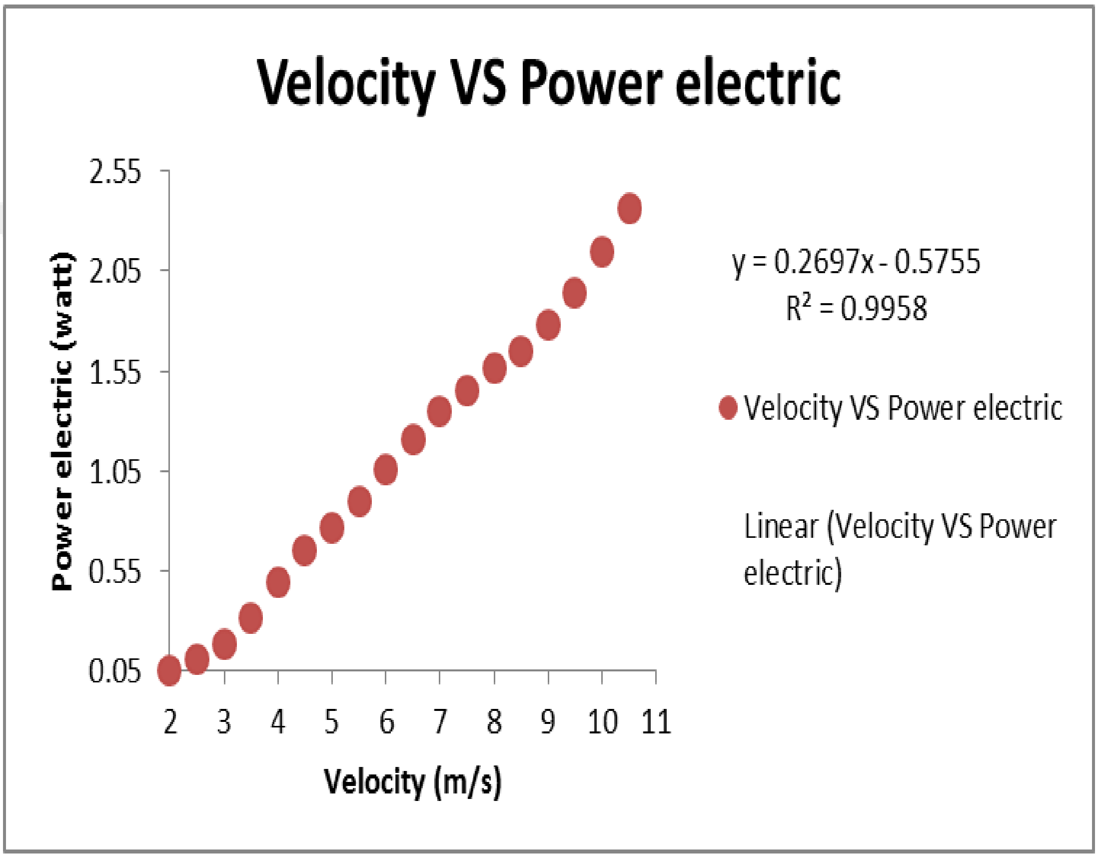


Figure 4.4a relation between velocity and electrical power of five blade rotor.

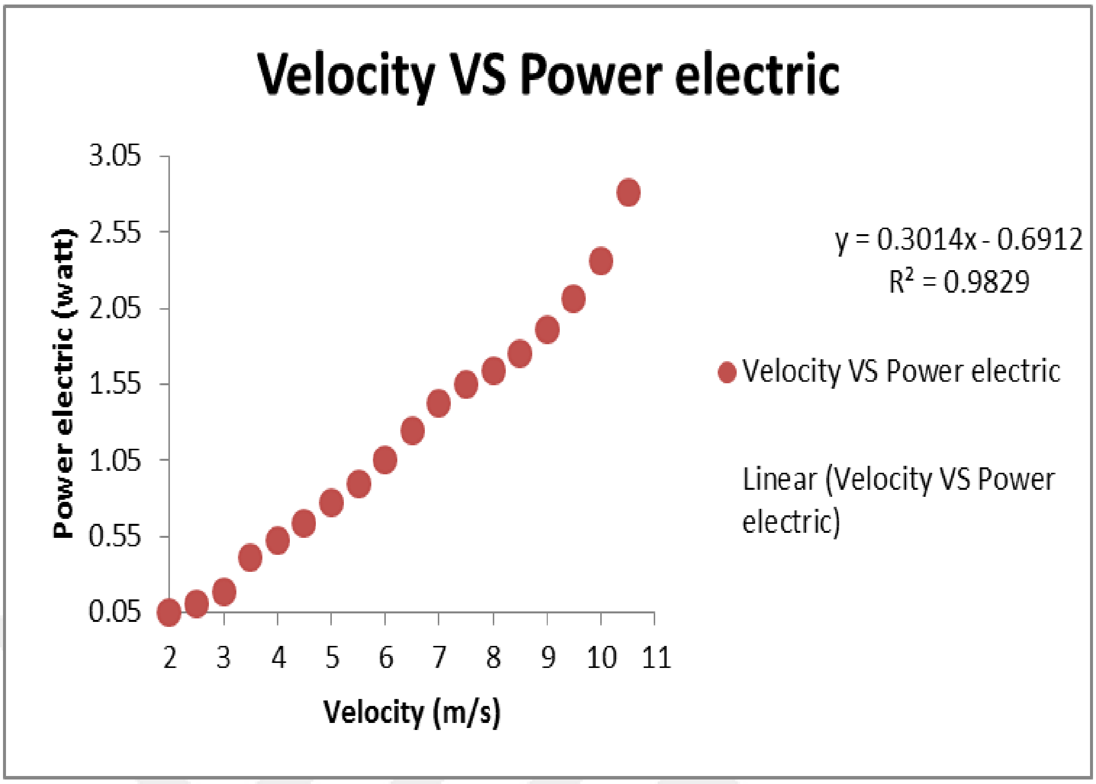


Figure 4.4b Relation between velocity and electrical power of two blade rotor.

The relationship between wind speed and electric power which calculated by equation (3) is shown in the graphs above (figures 4.4a and 4.4b). Where the graph shows that the two-blade rotor up to (2.81 W) while the five-blade rotor up to (2.36 W) at the same wind speed obtained for both models is (10.5 m/s) (see Table1 and Table2). It seems that the two-blade rotor is better than the counterpart in generating electricity for the same generator and load. The reason is explained in Figures 4.2a, 4.2b, 4.3a and 4.3b, which shows the generation of voltages and current respectively for both models.

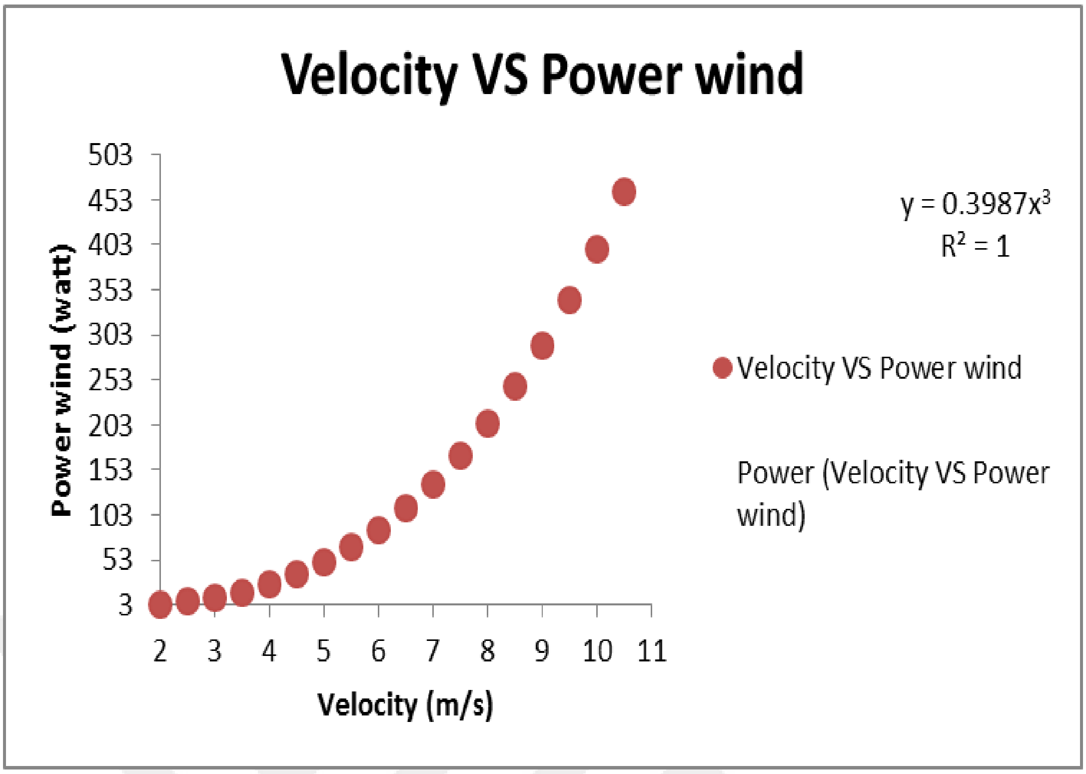


Figure 4.5a Relation between velocity and power wind of five blade rotor.

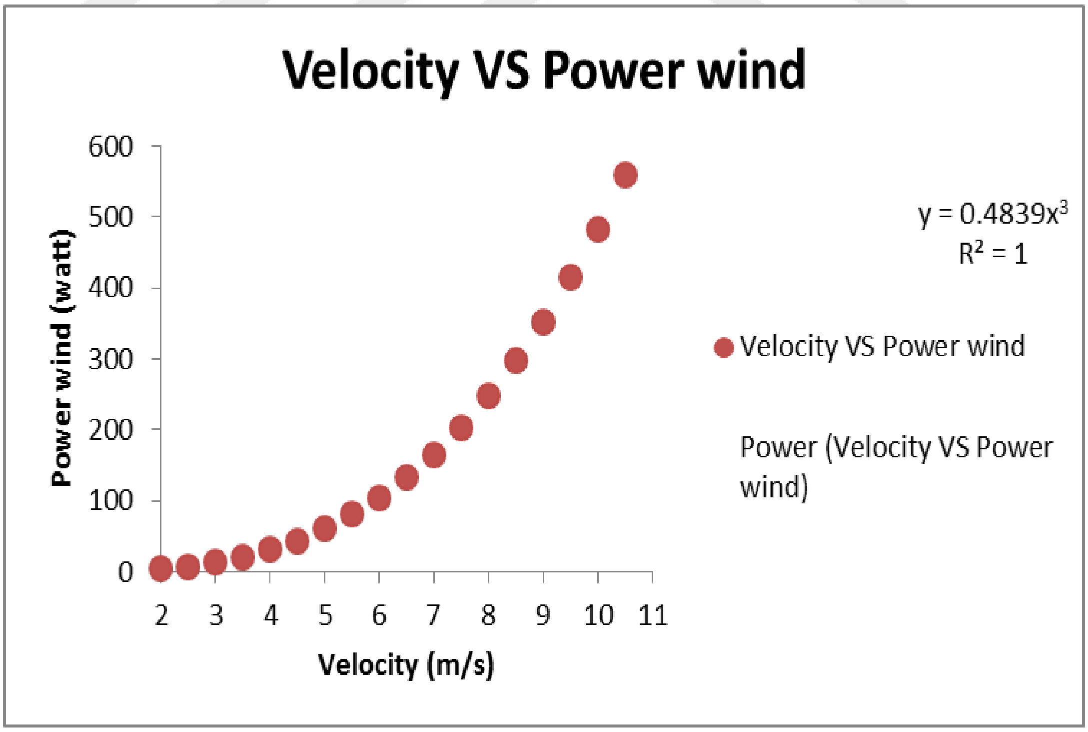


Figure 4.5b Relation between velocity and power wind of two blade rotor.

The graph above shows the difference in wind power that calculated by equation (2) with different wind speeds in order to check the rotor capacity. The figures 4.5a and 4.5b showed the two-blade rotor gives wind power up to (560.145 W) but the five-blade rotor reaches (461.588 W) at the same maximum wind speed (10.5 m/s) (see Table1 and Table2). Thus the two-blade rotor is more efficient than the counterpart in this work. The reason for that is the diameter of the two-blade rotor blades are greater than the diameter of the blades of the corresponding model, allowing the wind to have wider areas to strike, which leads to the rotor's ability to rotate more and more.

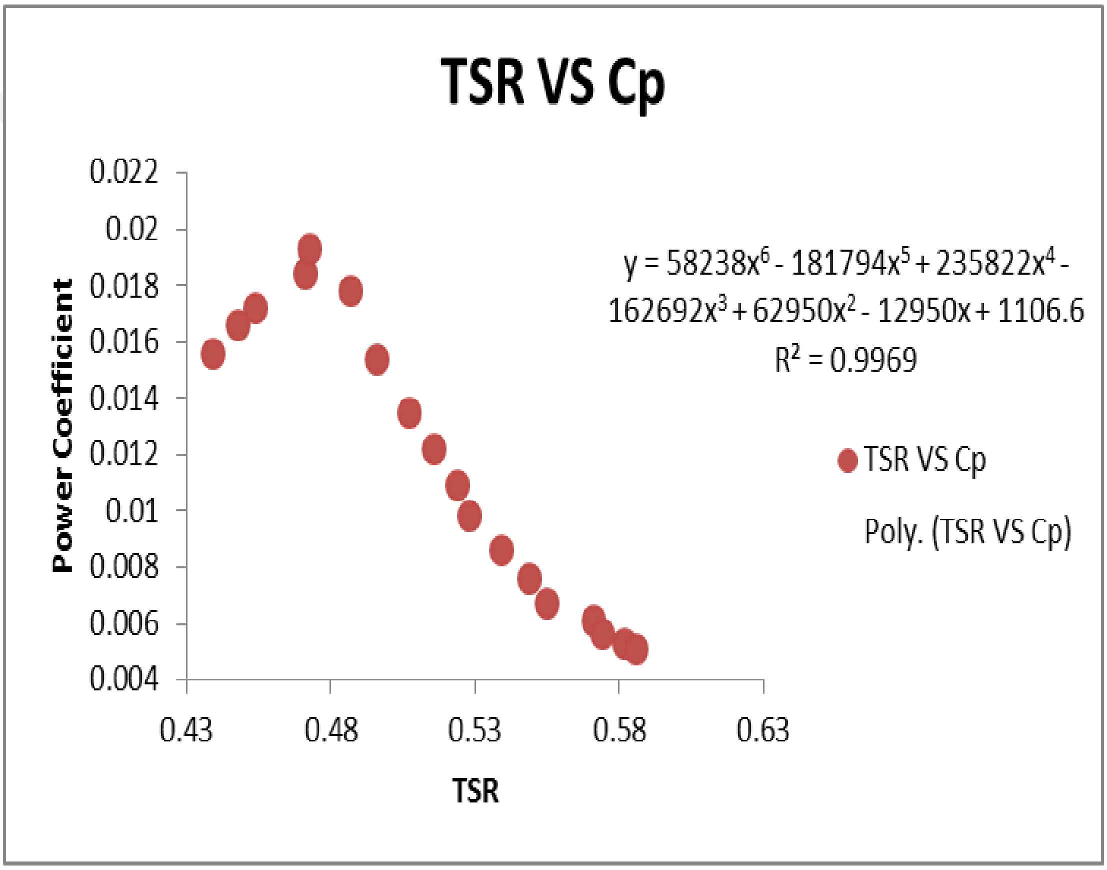


Figure 4.6a Relation between TSR and power coefficient of five blade rotor.

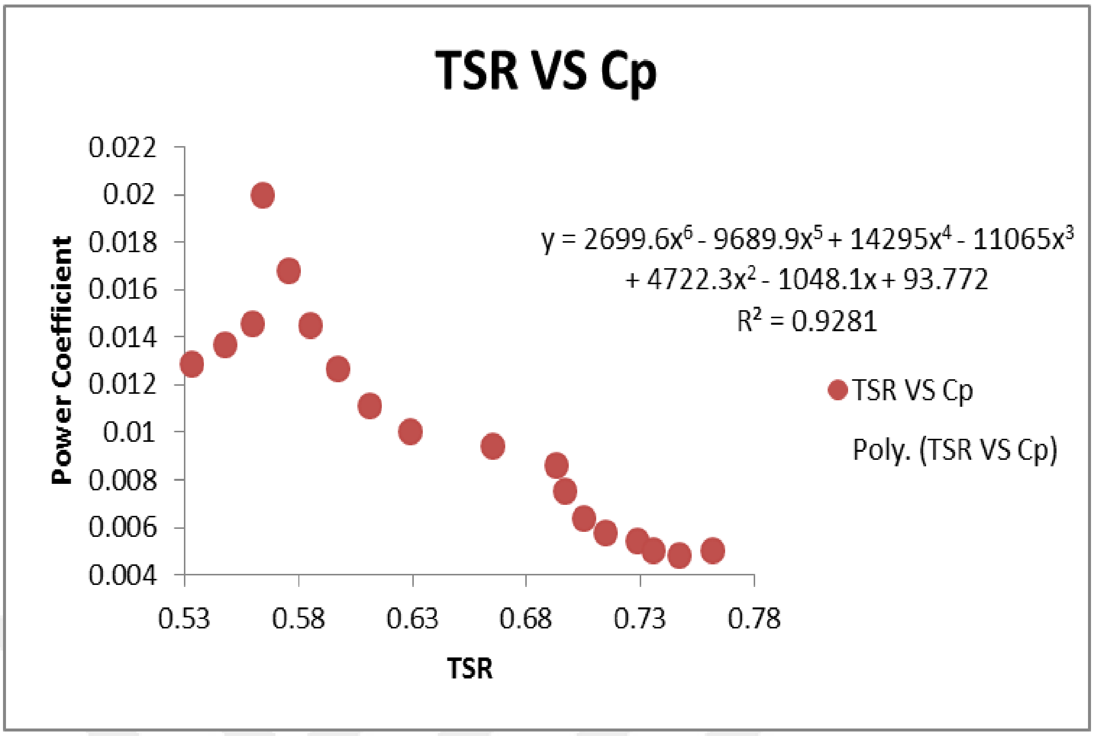


Figure 4.6b Relation between TSR and power coefficient of two blade rotor.

Figures 4.6a and 4.6b appear the relationship between the power coefficient, which done calculated by using equation (4) and the tip speed ratio that production from the equation (6) of the rotor made from the conventional barrel by changing the number of blades between two blades and five blades to investigating performance of each model by using the same material of hardness, thickness, alternator and load. The two-blade rotor showed the maximum power coefficient (0.02) at the tip speed ratio of (0.564) while the five-blade rotor reaches the maximum power coefficient (0.0193) at the tip speed ratio (0.472) (see Table1 and Table2). Indicating that the two-blade rotor has better efficiency than the corresponding model in this work.

CHAPTER 5

CONCLUSIONS

This research investigates the performance of vertical axis wind turbine models based on the drag force under normal climatic conditions from wind speed, temperature and pressure. Two models are blades different were used to determine the effect of changing the number of blades on performance it. It has the same material, hardness, thickness, turbine height, end plates, electric generator and load. The first model is made of a traditional barrel containing five blades of the amount of angle between it 70º while the second model contains two blades the amount of angle between it 180º. Performance coefficients for both models were determined under variable wind speed for every 5 minutes at 12 hours per day.

1. Rotor with two blades up to 150 RPM at 10.5 m/s while the five blades up to 140 RPM for the same wind speed.
2. The two blade rotor has power coefficient highest value of (0.02) at the tip speed ratio of (0.564), the five blades have a value of (0.0193) at the tip speed ratio of (0.472), this means that the two-blade rotor has better performance than the five-blade rotor.
3. The two-blade rotor generated (12.8) volts, while the five-blade rotor generates (11.8) volts, at the same wind speed 10.5 m/s. This is because the ability of the two-blade model to rotate more than five blades leading to an increase in the number of generators rotate responsible for generating this voltage.

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