AUGUST 2018

M.Sc. in Physics Engineering

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UNIVERSITY OF GAZİANTEP GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

EXPERIMENTAL PERFORMANCE INVESTIGATION OF ELECTRICAL ENERGY PRODUCTION SYSTEM BY USING VERTICAL BARREL WITH 3 AND 4 BLADES FROM WIND ENERGY IN GAZIANTEP CONDITION

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IN

PHYSICS ENGINEERING

BY

BASIL HAJNAASAN

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Experimental Performance Investigation of Electrical Energy Production System by Using Vertical Barrel with Three and Four Blades from Wind Energy in Gaziantep Condition

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in

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Supervisor

Assoc. Prof. Dr. Rabia Güler Yıldırım

by

Basil HAJNAASAN

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Basil HAHNAASAN

ABSTRACT

EXPERIMENTAL PERFORMANCE INVESTIGATION OF ELECTRICAL ENERGY PRODUCTION SYSTEM BY USING VERTICAL BARREL WITH 3 AND 4 BLADES FROM WIND ENERGY IN GAZIANTEP CONDITION

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Savonius turbine is one of the Vertical Axis Wind Turbines(VAWT) that rely on wind power and is less efficient than turbines with a Horizontal Axis Wind Turbine(HAWT) but VAWT has several good properties not found in the HAWT.

VAWT do not depend on wind direction and do not need a self-start force. It can also be installed in relatively low places compared with HAWT turbines. VAWT has better efficiency than HAWT at low wind speed places.
This thesis discusses the performance of the Savonius Rotor manufactured from empty barrels of oil. Two models manufactured, three blades rotor and the other with four blades. The performance of each turbine was studied in the climatic conditions of Gaziantep city.
The rotational speed of the turbine for both models started from 20 rpm. Each model was studied separately. The current and voltage of the rotors generator were taken for both models and compared to distinguish the turbine with the best performance.

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

ÖZET

GAZİANTEP ŞARTLARINDA DİKEY BİR VARİL (3-VE 4 KANATLI) KULANILARAK RÜZGARDAN ELEKTRİK ÜRETEN BİR SİSTEMİN VERİMİNİN DENEYSEL ARAŞTIRILMASI

HAJNAASAN, Basil
Yüksek Lisans Tezi, Fizik Mühendisliği
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Ağustos 2018
44 sayfa

Savonius türbini dikey eksenli rüzgâr türbinlerinden biridir (VAWT), rüzgâr enerjisine dayanır ve yatay eksenli rüzgâr türbinlerinden (HAWT) daha az verimlidir. Ancak HAWT'de bulunmayan birkaç iyi özelliğe sahiptir. VAWT rüzgâr yönüne bağlı değildir ve kendi kendini başlatma kuvvetine ihtiyaç duymaz. Ayrıca HAWT türbinlerine kıyasla nispeten düşük yerlere kurulabilir. VAWT, düşük rüzgâr hızının yerlerinde HAWT'den daha iyi verimliliğe sahiptir. Bu tez, boş petrol varillerinden üretilen Savonius Rotorunun performansını tartışmaktadır. İki model üretilmiştir, üç kanatlı rotor ve diğeri dört kanatlıdır. Her bir türbin performansı, Gaziantep şehrinin iklim koşullarında incelenmiştir. Her İki model için de türbinin dönmesinin hızı 20 rpm'den başlamıştır. Her model ayrı ayrı incelenmiştir.

Her iki model için de rotor jeneratörünün akımı ve Voltajı alındı ve türbininin en iyi performansıyla ayırmak için karşılaştırılmıştır.

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

To my father, my mother, my wife and my children

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I thank Assoc. Prof. Dr. Rabia Güler Yıldırım, who is one of the most important persons that inspired me to complete the master's study by her knowledge and wonderful dealing with all students.

I thank my father, the person I trust, who is the only person will be happier than me in my master certificate and to my mother, I always believe with her braying to me, and to my dear wife I love her very much and my children.

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LIST OF SYMBOLS

Symbol	**Explanation**
VAWT	Vertical axis wind turbine
HAWT	Horizontal axis wind turbine
H	Rotor height
D	Blade Diameter
A	Rotor Area
d	Rotor Diameter
V	Wind velocity, m/s
N	Rotational speed, rpm
λ	Tip Speed Ratio
T	Torque
I	Electric Current
V	Voltage
AC	Alternating Current
Cp	Power Coefficient
Pa	Wind power
Pe	Electric power

CHAPTER 1
INTRODUCTION

Because of the lack of resources, huge costs and pollution resulting by using non-renewable sources of energy. Even fossil fuels in Turkey are few, and are expected to be unable to cover their future needs of coal oil and gas. Therefore, empirical research is needed to improve the production and efficiency of alternative energies, are less expensive and not harmful to the environment. Wind energy is one of the most important of them [1], since we use it in many places and fields where electrical grid couldn't be found, but one of the challenges of this energy is its relation to the changes of climate .However, using such energy has spread recently in the world, especially in Turkey, where the using of this energy in air passages of mountains is common, where the wind speeds are high causing improvement of agriculture in the fields and contributed to the industrial revolution witnessed in Turkey and is still recognized to this moment [2].

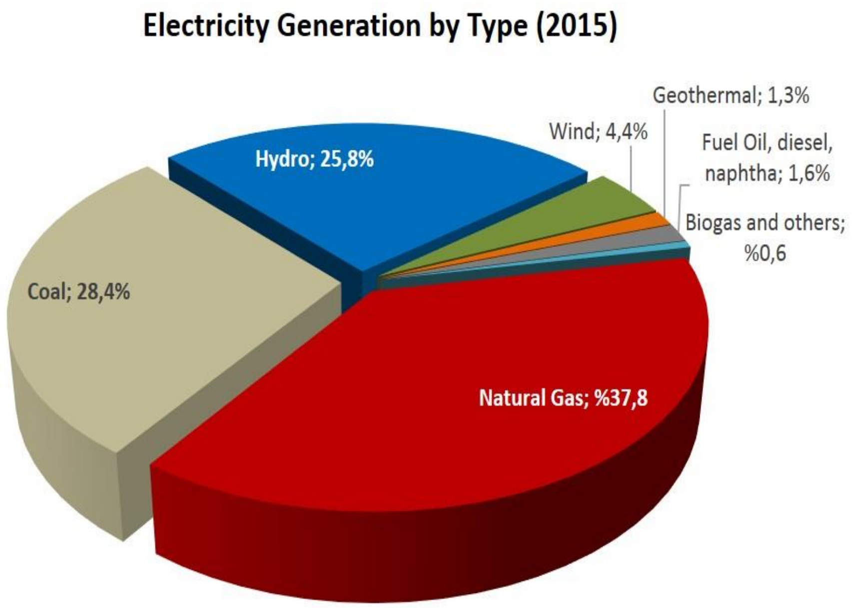

Figure1.1 The generation of electricity in Turkey [3]

	Installed capacity today	2019 targets	2023 targets	
		Strategic Plan 2015-2019	Original 2023 targets	2023 targets in NREAP
Hydropower	22.29	32	Max. economi-cally feasible	34
Wind	2.76	10	20	20
Solar	0	3	3	5
Geothermal	0.31	0.7	0.6	1
Biomass	0.22	0.7	-	1
Overall Renewable Capacity	25.58	-	-	61
Overall Installed Capacity	64	-	120	125

Figure 1.2 Renewable energy policy targets of Turkey in GW [4]

1.1 Wind Turbine

Wind turbines turn mechanical energy into electrical energy and there are two types of wind turbines horizontal axis and vertical axis

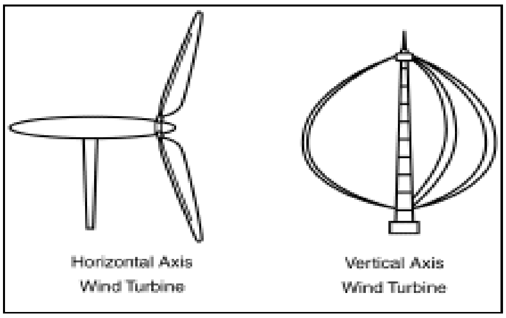

Figure 1.3 Horizontal axis and vertical axis 4

The most common use is horizontal axis wind turbines because it is highly efficient and is the older than vertical axis, however vertical axis turbines have some advantages do not exist in horizontal axis [5], as they are easy to manufacture and most of VAWT do not need self-start speed and can be easily installed. It does not require the same transportations effort as horizontal axis turbines.

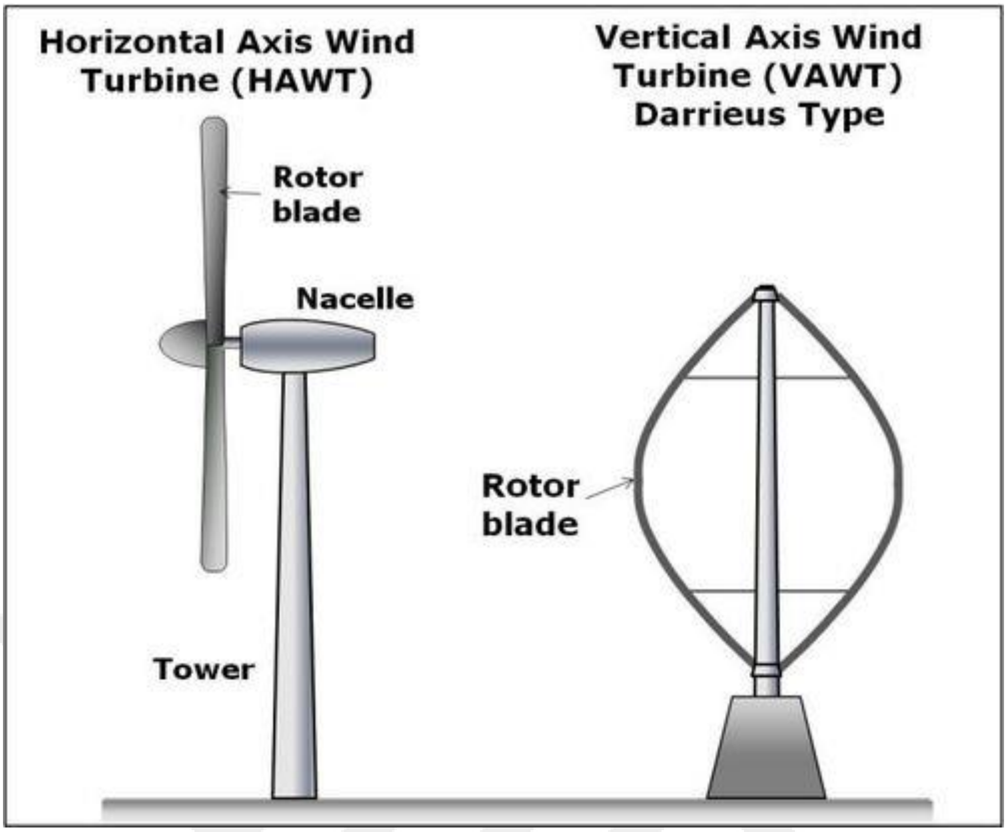

Figure 1.4 Horizontal axis turbine (HAWT) and vertical axis turbine (VAWT)

Vertical axis turbines do not rely on wind direction and can generate electricity at low wind speeds, unlike horizontal axis turbines [6]. In this research there is a benefit in recycling from empty barrels which used in oil transport where it can be recycled as vertical axis turbines.

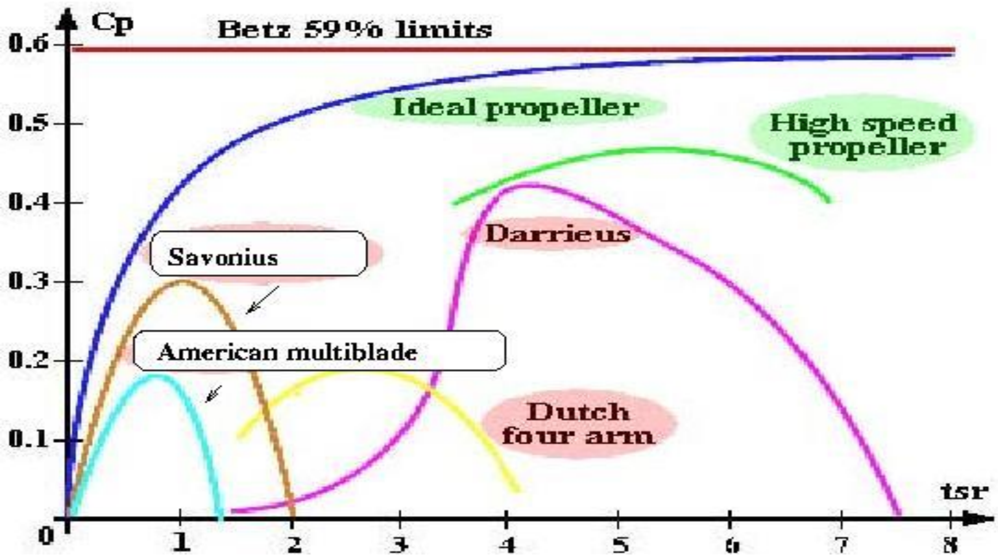

Figure 1.5 Power Coefficient (Cp) vs. tip speed ratio (λ) for various wind turbines [7]

1.2 Vertical Axis

Vertical axis turbines consist of two types, depending on the driving force, the drag force and the lifting force, so that the drag force is the easier type of assembly and production like Savonius rotor [8]. The more complex type is the lifting force like Darrieus rotor

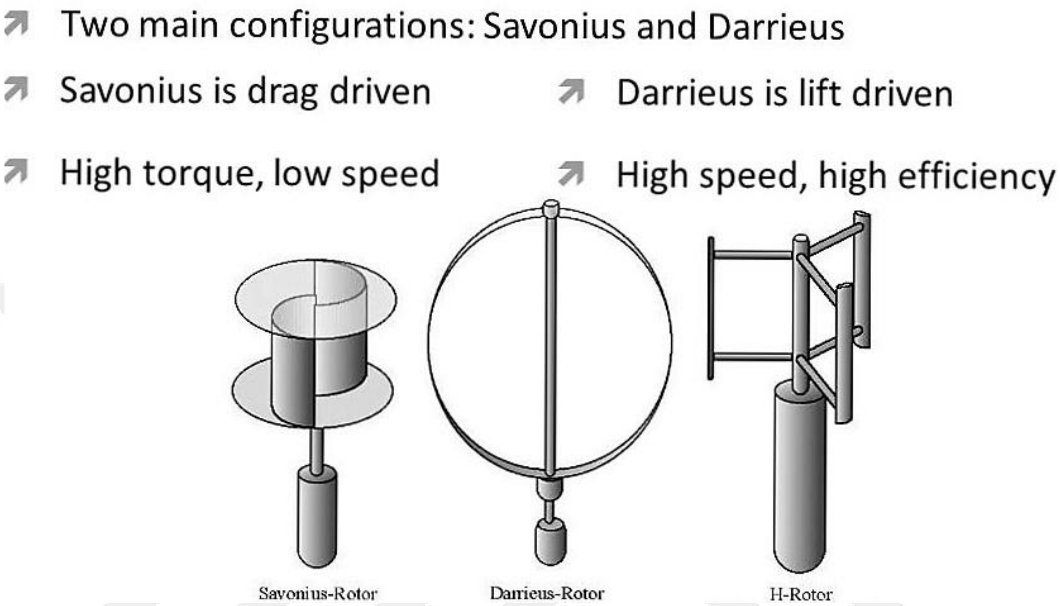

Figure 1.6 Drag and lift type of vertical axis wind turbine and the basic differences between them

1.2.1 Savonius Rotor

Savonius Rotor used as a water bumps, electric power generation, ventilation systems and agitating water to keep ponds in winter not frozen. The principle of the Savonius rotor depends on the drag force in the concave and convex blades, but the efficiency of the Darius Rotor is higher than the Savonius rotor [9].

Figure 1.7 Savonius rotor turbine

1.2.2 Darrieus rotor

The energy of moving in this type of rotor is a lifting force, and the lift force is vertical to the resultant of the wind speed, and relative velocity from airfoil to the shaft. Darrieus Rotor has faster rotational speed than Savonius and consequently the efficiency is higher, but this type suffers from low starting torque and it is not self-starting [10].

Figure 1.8 Darrieus rotor turbine

1.3 Thesis Aims

The main aim of this thesis is to learn the characteristics of two Savonius wind turbines (three and four blades Savonius rotors) and compare between them in order to reach to the higher efficiency in electric power generation and enhance the study in this fieldBelow steps were followed to reach this goal.

1 Manufacturing two Savonius turbines with three and four blades manufactured from recycle an empty oil barrel.

2 The measurements were taken for a period of four months. The wind speed and rotational speed of each Savonius rotor were measured separately.

3 Calculating both of electrical current and voltage which generated from turbines generator and compare the three blade turbine with the four-blade turbine.

4 Both power coefficient and tip speed ratio were calculated and compered with experimental results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Savonius Turbine is easily used in remote areas, especially for electricity generation, where it is activated in fields where grids is not reached. Numerous studies have been carried out on the manufacture and geometry of the Savonius turbine (VAWT) and many modifications have been made to improve the performance of this turbine.

Figure 2.1 Savonius turbine

2.2 Geometry of Savonius rotor

The most important thing in Savonius rotor is the geometry of the rotor like placed the blades in ways that make the performance better like a managing the gaps and over labs between the blades, both the blade radius and the height of the turbine and the thickness of the blades, above that one of the most important was the number of stages in one rotor.The addition equipment to the Savonius improved the performance of the turbine 6, moreover the additional shield to Savonius blades, gave a better result in the efficiency, in addition the experiments used the dispersion of the plates and added the ends in the Savonius turbine. Many studies about the twisted rotor and helical Savonius turbines have been done, and in this field many experiments have made in the twisting angle and helical angel at the savonius rotor to achieve more rotational speed in the rotor [11], thus higher efficiency in the turbine Several modifications have been made to the Savonius Turbine to improve performance.

2.2.1 Twisted Savonius turbine

In the present study it has been found that the twisted of the blades in the Savonius turbine has a positive effect on the efficiency of this rotor [12]. The twisted angel's blades are ranges from 0 to 25 and it is remarkable that the performance of the Savonius turbine in the twisted angle 0 (semicircular blades) has a bad performance comparing with other angels The twisted angle is proportional to the wind speed and the optimum angle of the twisting in the blade is 15 degrees at wind speed 6.5 meters per second [13]. The reason for the higher efficiency of the twisting rotor comparing with semicircular rotor is The maximum force of the wind speed strikes the concave blades in the middle while the twisted rotor the force reaches the top of the blades because of twisting in the rotor therefore more long moment arm, which gives more rotational speed and thus higher efficiency

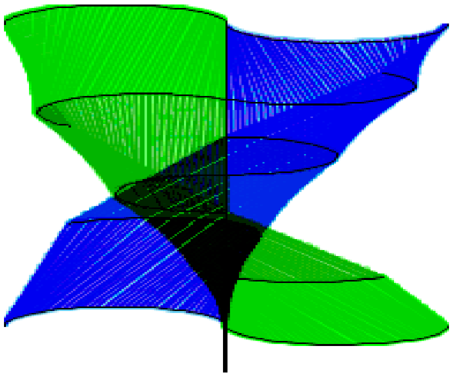

Figure 2.2 Twisted in savonius rotor

2.2.2 Helical Savonius rotor

In addition to the twisted angle in the blades of the Savonius rotor, the helical angle was added in order to reach the optimum performance in Savonius turbine[14], several helical angles of the helical turbine were studied from 0 to 360 and the optimum angle was 45 [15]

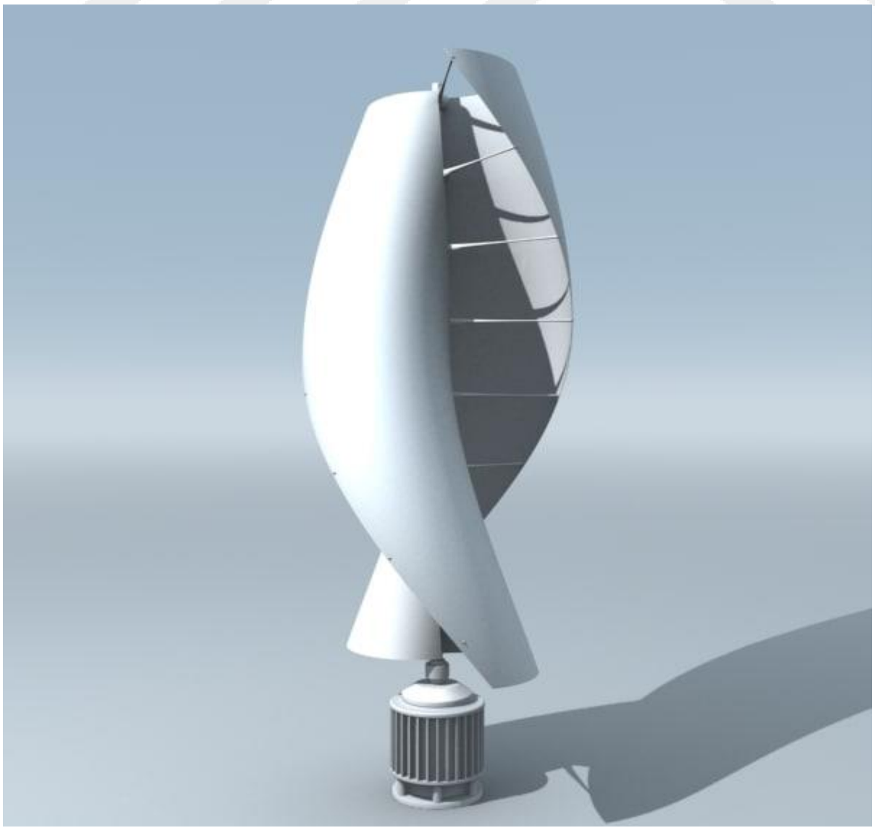

Figure 2.3 Helical rotor

2.2.3 Number of stages

The efficiency of the Savonius rotor also depends on the number of stages, the experiments has done from the stage number 1 to 3 to know the optimum number of stages. The turbine shows better properties when the number of stages increases from 1 to 2, but in contrast the performance decreases when the number of stage increases from 2 to 3.

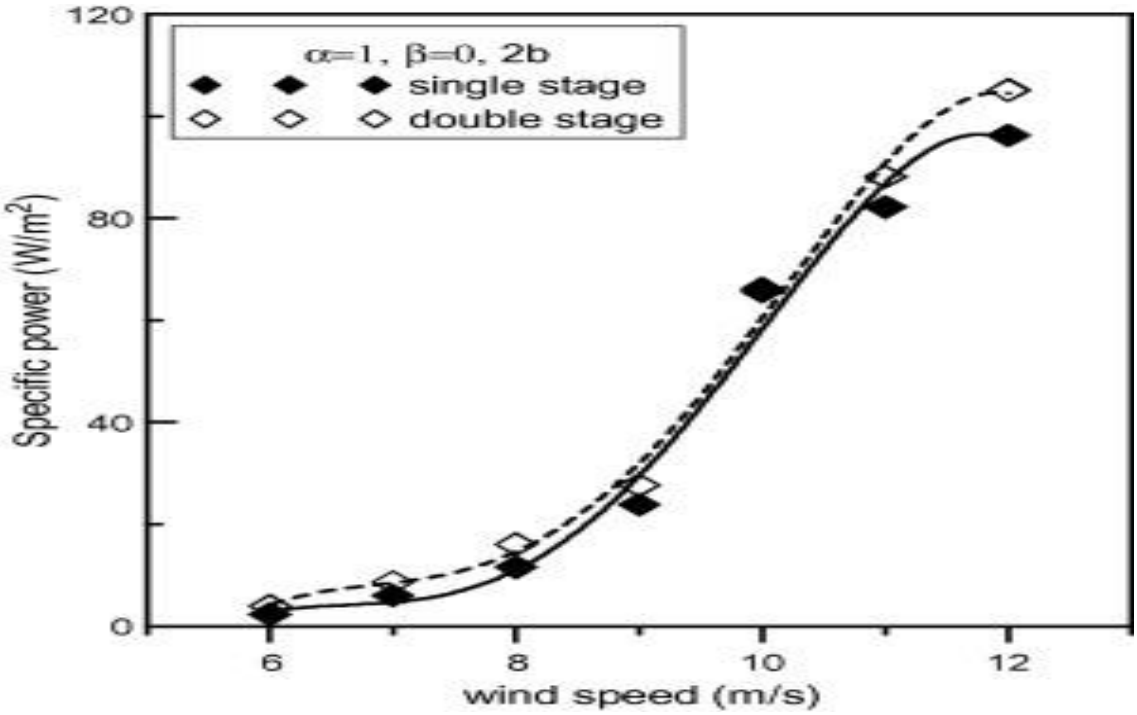

Figure 2.4 The graph of the relation between wind speed and energy in single stage and double stage

This is due to the fact that the inertia of the turbine increases in stage 3. however, the optimal stages number is 2 in Savonius turbine fig. 2.5 [16]

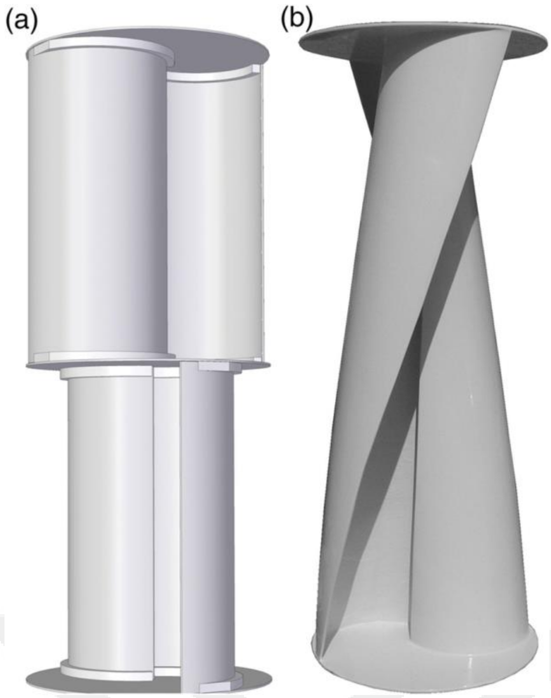

Figure 2.5 The multiply of stages and the twisted in Savonius Turbin

2.2.4 Savonius Bach

Savonius Bach Is the second Savonius which has been discovered after the traditional Savonius1[17], in Bach Savonius he replaced the semicircular blades with a spherical blade consisting of a straight line and ending with a shape of arc. the experiments have studied both the traditional Savonius and Savonius pach, Savonius's performance was found to be the best in the normal and little average of the tip speed ratio but in the high average of tip speed ratio the traditional Savonius is more efficiency. [18]

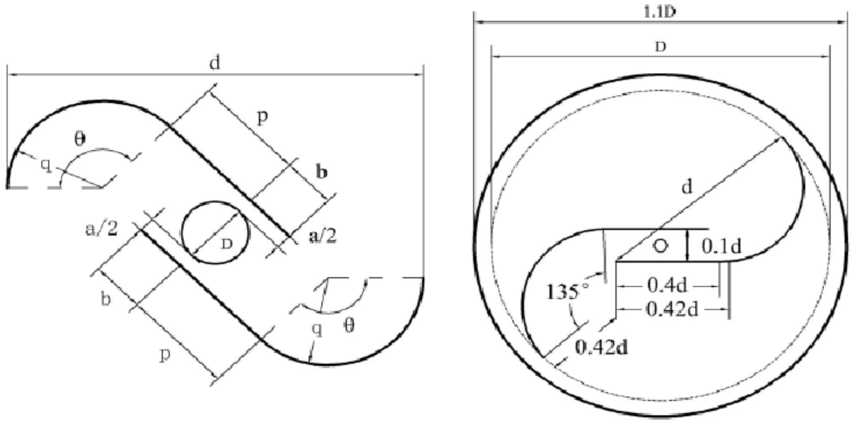

Figure 2.6 Shape of blade in Savonius pach [19]

2.2.5 The Sivasegaram Savonius

Blades in Savonius rotor is composed of a straight line and arc, while Sivasegaram Savonius consists of two arc [20], one with a large bend and the other with a smaller bend as in the figure (2.7). This type was created because its efficiency is better than traditional Savonius and has a good out put

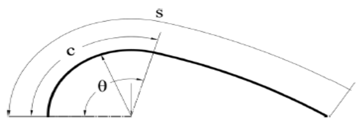

Figure 2.7 Shape of blade in Sivasegaram Savonius

2.2.6 Number of blades

The number of blades was studied in the Savonius rotor and the two blades was the optimum number of blades. It was observed that the performance of the turbine decreased when the number of blades increased from 2 to 3 [21], and the performance decreases when the number of blades increases to 4 and 5. This is due to the fact that when increasing the number of blades, the wind that strike the blade will bounce back to the nearest blade and have a negative impact on this blades rotation through the negative torque which slows the rotational speed of the rotor and thus has a negative effect on the efficiency of the turbine. Experiment of several rotors with different number of blades shows, when blades are closer to each other's (more numbers of blades) it causes a negative impact on the efficiency of the rotor The studies shows that the optimal number of blades is two blades. [22]

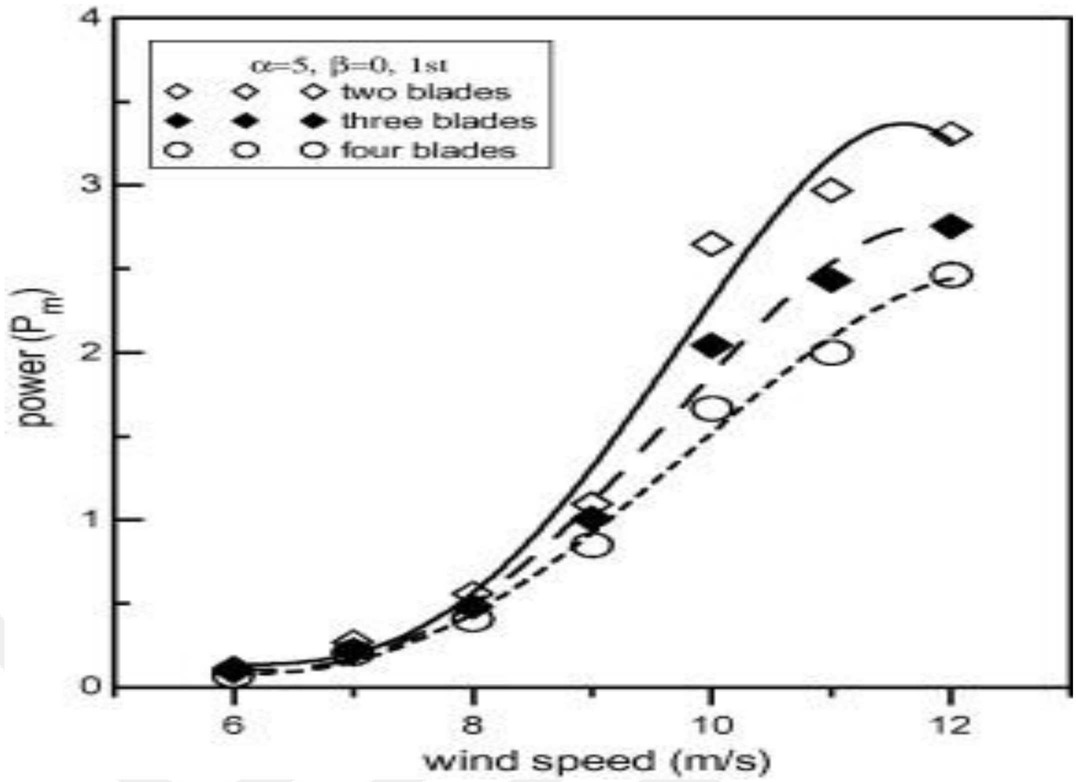

Figure 2.8 The graph of the relation between the wind speed and the power of turbine in different numbers of blades in Savonius rotor

2.2.7 Aspect ratio and overlap

Aspect ratio is the ratio between Height of the rotor (H) and rotor diameter (D) and many researches how studied this ratio. It was noticed that the performance of the rotor decreases with the increase of this ratio[23] and it is clear from fig2.10 that's the perfect value of overlap is 0 [24].

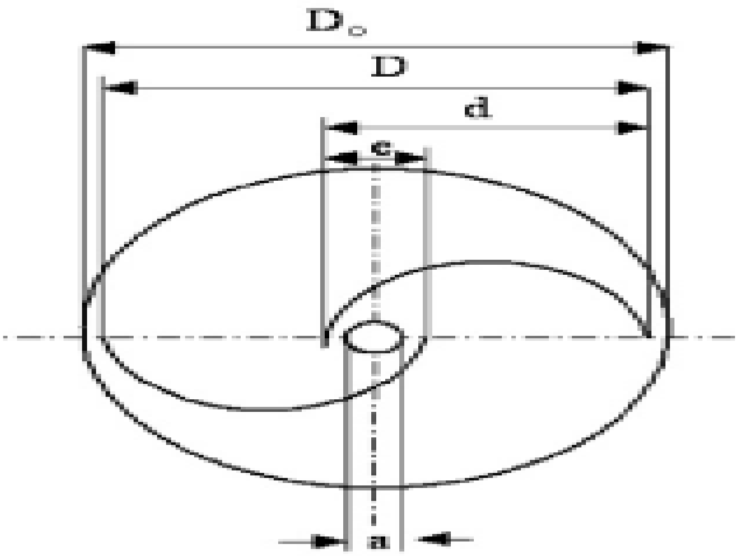

Figure 2.9 Overlap of the blades in the rotor

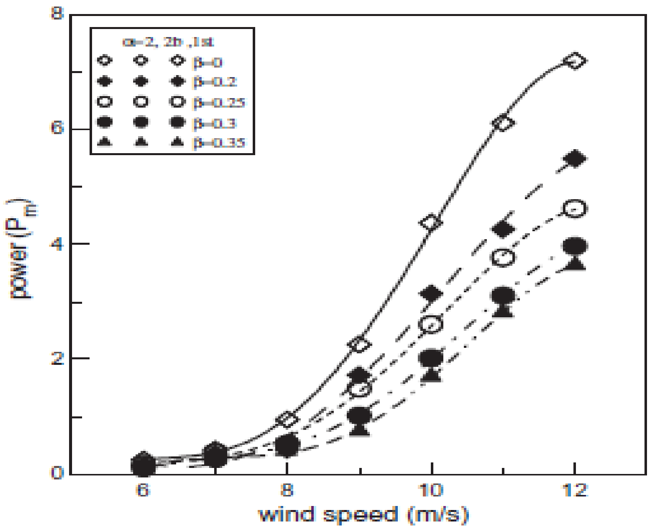

Figure 2.10 Graph between wind speed and power of different values of overlap

2.2.8 Betz limit

The most important characteristics of turbine capacity is efficiency, but this efficiency cannot be up to 100%, i.e., the whole wind energy coming to the turbine does not turn into a mechanical energy to rotate the turbine. There is a loss of energy for many reasons, like the forces of friction in the blades, and the returns speed of wind that hit the nearest blade in turbine, thus its impact with a negative torque on turbines rotation [25], and in-depth study of the German engineer Albert Betz in 1919_ found that the ideal efficiency ratio is impossible and the highest percentage of efficiency can reach

59% this percentage called Betz limit. This percentage without calculating the loss of energy while changing from mechanical energy to electrical energy.

2.3 Darrieus rotor

The Darius Rotor is characterized by the lift force in its rotation. As in the Savonius Rotor, several modifications have been made to this turbine to increase its efficiency. The Darrieus turbines types in general is divided to three types Darrieus rotor , Helical Darrieus rotor , and H type Darrieus rotor.

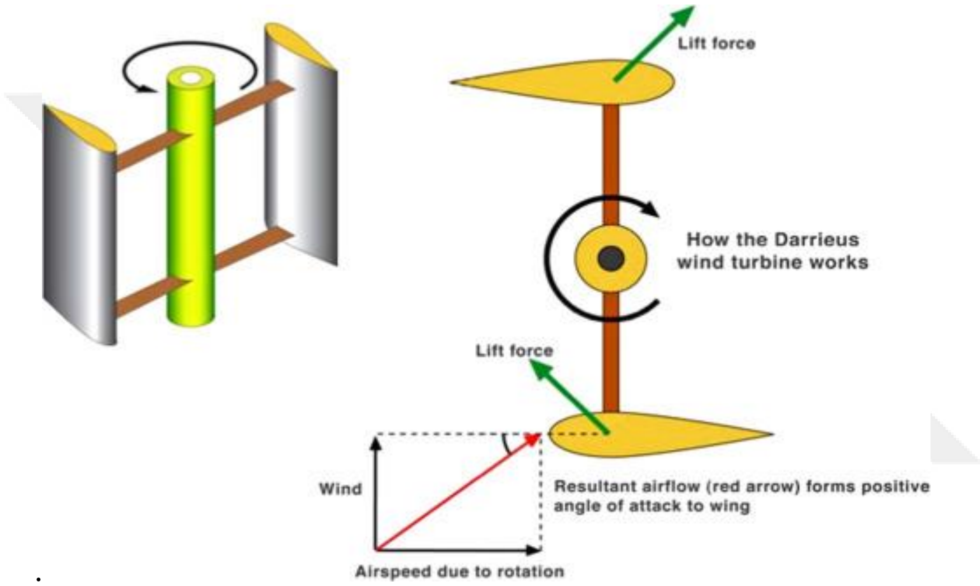

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Figure 2.11 Darrieus rotor and Lift Force

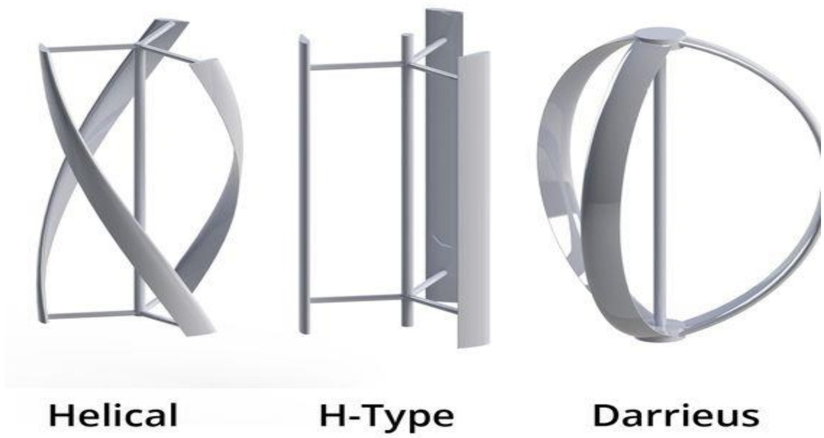

Figure 2.12 Types of Darrieus rotor

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter of thesis, the aerodynamic properties of the VAWT with vertical axis have been studied experimentally for several blades. All test measurements were carried out in Gaziantep weather with temperature, pressure and wind velocity in the city, in order to distinguish between the existing models of VAWT in terms of torques efficiency, and power efficiency.

With more precisely, this chapter discussed the difference between the two types of VAWT rotor with three and four blades through experiments and how to obtain more electrical power from the turbine with the appropriate equations.

3.2 The turbine

The vertical axis turbine VAWT is one of the simplest turbine types, which depends on the principle of conversion wind energy to mechanical energy then to electric energy by a generator connected with rotor, many researches have been several experiments to improve the performance of this turbine because of its positive impact on the environment compared with fossil fuel whish consider the most harmful resources effect on environmental by their pollution. It is known that this type of turbine does not depend on the direction of the wind, and it does not require high places as it is able to produce energy in low places, and VAWT is easy to manufacture.

In this study, the rotor is manufactured from empty barrels of oil as a contribution to the recycling process, which gave it good and cheap properties, the performance of This turbine is low compared with the horizontal axis turbine.

3.2.1 The First Model

An empty oil barrel was opened to three blades where the diameter of the barrel was (58 cm), the length of the barrel (77.5) and it's the length of the rotor, the angle of bending of each blade of the barrel (120º) and the radius of the turbine is (47 cm)and the thickness of the turbine is (1.33mm) fig 3.1

Figure 3.1 Model 1 Savonius with three blades

3.2.2 The Second Model

The same type of barrel was taken in the first model with a thickness (1.33 mm) and the length of the turbine is (77.5) the barrel is opened to four blades and the radius of the turbine is (44.5 cm) and the bending angles of its blades were equal (90º) fig 3.2.

Figure 3.2 Model 2 Savonius with four blades

Our research of the two models can be divided into two main sections: mechanical and electrical.

3.3 Mechanical Section

The main objective of this section is to convert wind energy into mechanical energy through several parts and this mechanism:

In both models, a pulley (58cm diameters) is added at the bottom of the turbine by welding it to barrel and placed another pulley in the top of electric generator. The both pulleys are connected by a flexible belt. Its main function is to convert the mechanical energy from rotors rotation to electrical energy by rotating the generator pulley as shown in Fig 3.3.

Figure 3.3 The belt and the pulleys in the rotor.

The length of the shaft in the turbine is (290 cm), which is the high of the turbine and the diameter of this shaft is (7 cm). The opened barrel is placed in the upper part of the shaft and the shaft is fixed by heavy base has diameter (100 cm). This is a heavy base that is made of iron maintain the equilibrium of the turbine. The base gives more stability and prevents axis movement of the turbines axis as shown in fig 3.4.

Figure 3.4 Base with extra heavies

3.4 Electrical Section

It converts the mechanical energy into electrical energy through the rotation of the belt, the electrical system composed of several parts which work as follows:

3.4.1 Generator

The conversion of mechanical energy into electric power is through a generator connected to the rotor, which can give an electrical current DC for simple applications or AC electric current for more complex applications. In our experiment, the DC voltage was used and in this experiment washing machines generator was used (1500 RPM/min, 50 Hz). This generator consists of 2 and 4 neodymium magnet and pulley (5 cm diameter) was connected to generator as shown in fig 3.5.

Figure 3.5 The generator placed on the shaft

These generators are widespread because of their low cost and can connect multiple electrodes in this generator to the shaft.

3.4.2 The diode

The diode between the generator and the battery was designed to convert the electricity to DC and store it in the battery and the current was converted from AC to DC Because of illumination intermittently in AC current as shown in fig 3.6.

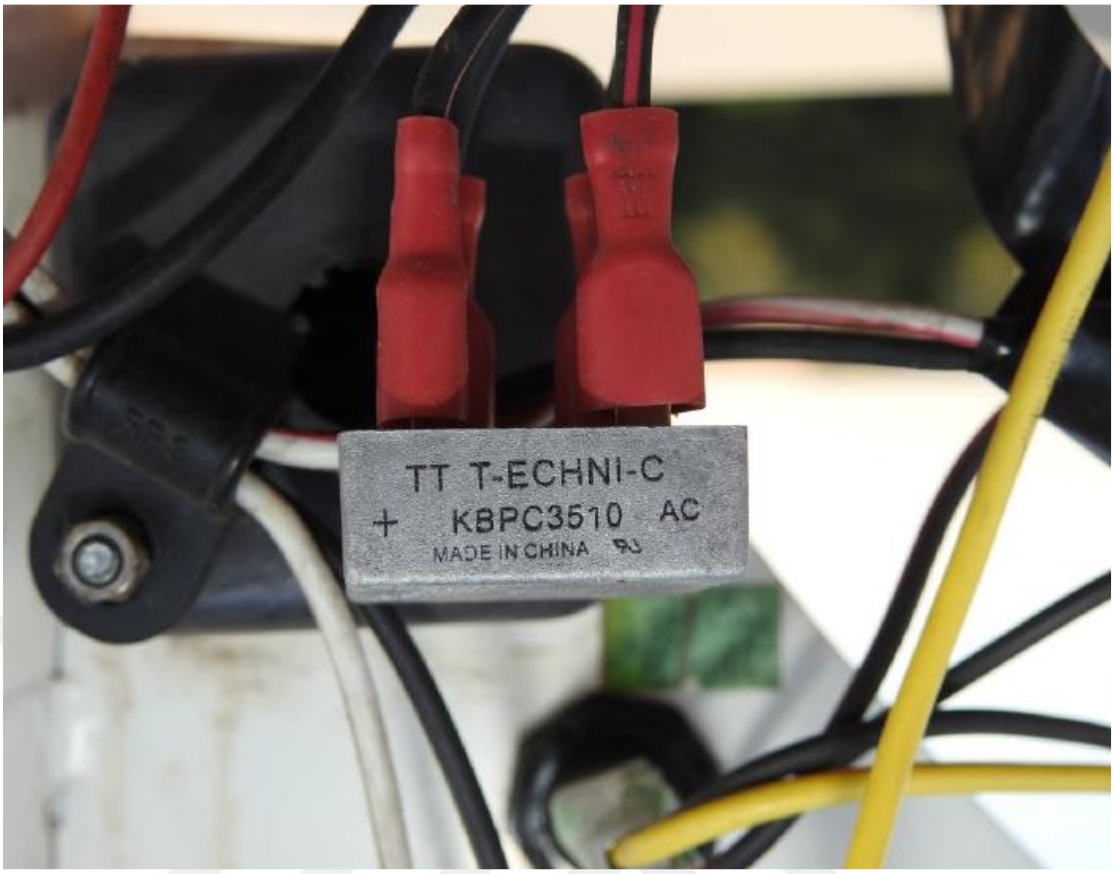

Figure 3.6 Diode bridge

3.4.3 Voltage regulator

The voltage regulator has been connected to protect from explosion if happened any overcharging in the battery that may lead to the explosion as in Fig 3.7.

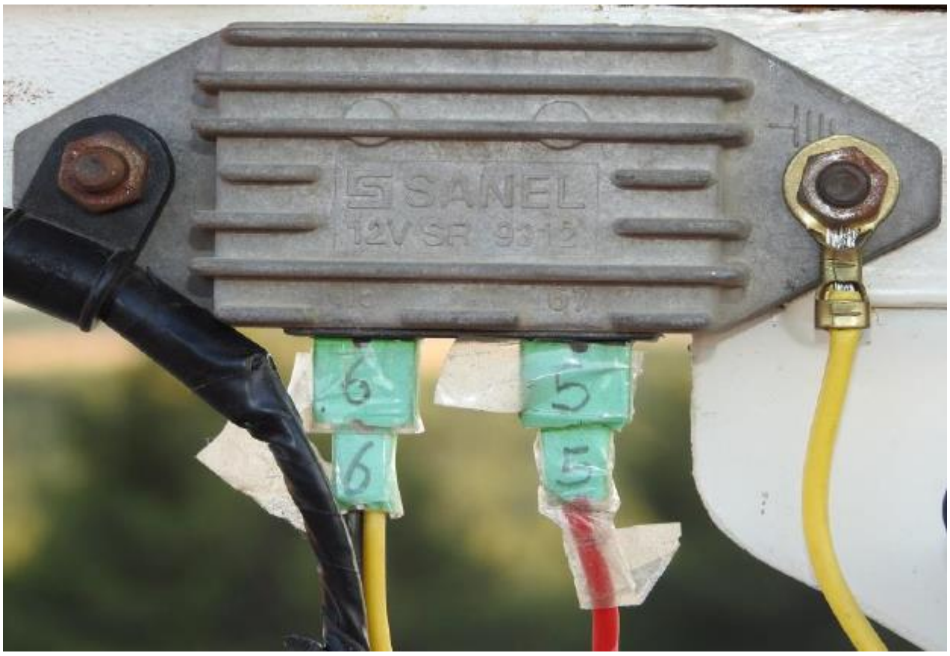

Figure 3.7 Voltage regulator

3.5 Test Set-up

The best and most suitable suggestions were to put the turbine on the roof of a restaurant called Seyirtepe Restaurant Which is located in the highest point in the Gaziantep University and the roof in this restaurant is open from four sides without Obstacles or windbreaks, which gives preference to this place for easy winds movement and the winds blow can make a turbines work from various directions. The rotor was manufactured and then transported to the restaurant roof.

The experiments began on the first November for three blades rotor and measurements continued for two months for the first model and on the first January the rotor with three-blades was replaced by another rotor with four blades pre-fabricated, and measurements for this model was taken for two months also so the total time for this experiment became four months

The working days were chosen when the wind speeds were relatively high in Gaziantep climate. On each working day, the measurements were taken in each 5 minutes for 12 hours from 10 am to 10 pm. The data taken and recorded are the rotational speed of the rotor, wind speed, electric current, voltage, temperature, and atmospheric pressure.

3.5.1 Wind velocity device

Wind speed was measured by the anemometer, which is installed against the direction of the wind (various directions), which gave the wind speed in meters per second as in fig 3.8.

Figure 3.8 Wind velocity device

3.5.2 Wind indicator

The wind indicator was used to determine the direction of wind blowing and to facilitate the measurement of its speed as in Fig 3.9. The anemometer measures the wind speed from 02 m / s to 30 m / s at 0.1 m / s punctuality.

Figure 3.9 Wind indicator

3.5.3 Rotational speed device

This device measures Rotational speed of the rotor at several different speeds and it is called a tachometer shown in fig 3.10

Figure 3.10 Rotational speed device

The reflective tape is bonded to the base of the rotor. The function of this tape is the infrared reflection emitted from the tachometer during the rotation of the rotor, the tachometer is placed at the bottom of the rotor and when the rotation reaches the reflective tape it reflects the light and shows frequency. In varying frequency with different time periods, the rotor's speed is measured in rpm unit.

3.5.4 Electrical devices

The electrical devices are placed on the shaft next to the rotor and this device consists of diode bridge, the power generator, resistive load, voltage regulator, and a simple circuit consisting of a 5-watt lamp was connected to the generator that gave the DC current as shown in fig 3.11,fig 3.12

Figure 3.11 Electric current and voltage measuring devices

Figure 3.12 Electric current and voltage measuring devices

3.6 Mathematical Expressions

In order to compare the two models in this thesis and compare these models with other studies, we must rely on non-dimensional coefficients power efficiency is the most represented value of the turbines capacity. and its ability to convert power. In addition to this value tip speed ratio represents the speed of the blades rotation to the speed of the coming wind to rotor .

Through the following equations we can calculate the tip speed ratio and energy efficiency of two models (3 and 4 rotors blades) for many wind speeds We can calculate the swept area (which is show in fig 3.13) from this equation

$$A = H.D \tag{3.1}$$

A: the area of the rotor , H: the rotors high , D: the rotors diameter

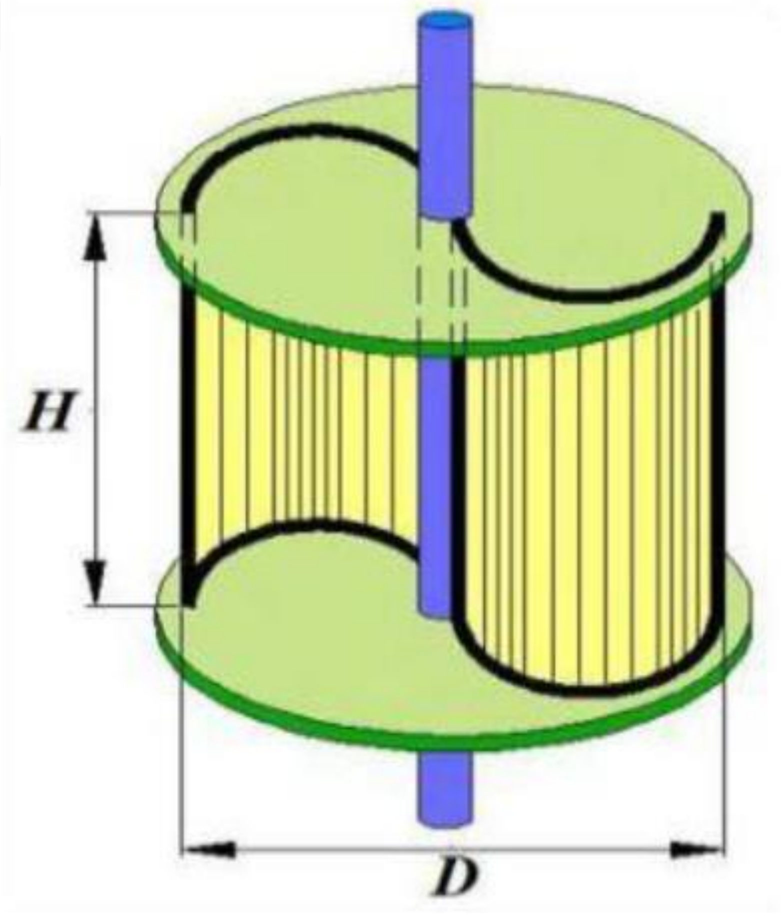

Figure 3.13 diagram of savonius rotor

the power coming from wind is given in equation:

$$P_a = \frac{1}{2} qAv^3 \qquad (3.2)$$

Where q *is* air density (kg/m^3) and v is wind velocity (m/s)

The generator provides electrical power:

$$P_e = I.V \qquad (3.3)$$

Where V voltage (v) and I electric current (A)

C_P power Cofficınt is given by equation:

$$C_P = \frac{Pe}{Pa} \qquad (3.4)$$

The angular velocity of the rotor W is :

$$\omega = \frac{2\pi N}{60} \qquad (3.5)$$

N rotational speed (rpm)

Tip speed ratio given in this equation:

$$\lambda = \frac{\omega d}{v} \qquad (3.6)$$

Where's d the radius of the rotor (m)

CHAPTER 4

RESULT AND DISCSSION

The most important variables in studies of vertical axis turbine are tip speed ratio and power coefficient. In this research two models were studied.

4.1 General

The first model is the Savonius turbine with three blades, which manufactured from empty oil barrel. The second model is also made from an empty barrel of oil but with four blades.

Where the most important criterion in different efficiency between the two models is the ability to generate electricity. All measurements were taken in the climatic conditions of the Turkish city Gaziantep.

4.2 The efficiency results

The most important characteristic on the efficiency of the turbine is Cp efficiency coefficient and the highest value in the Savonius Turbine is 0.59 in betz limit. Several things affects in The efficiency coefficient Cp , one of them the geometry of the turbine Also, the most important things affecting on the performance of the turbine is the tip speed ratio, which is related to both the geometry of the blades, its speed, and the speed of the wind coming to rotor , in other words, the speed of the blades , which can be changed by modification in VAWT.

the performance of the turbine represents by graph between the Cp and the tip speed TSR for better performance in the turbine, we can improve the modification to get better values in the tip speed ratio.

There are 32 tables for the measured results, for the rotor with 3 blades 16 Tables, and for the rotor with 4 blade 16 tables, in each table 144 Measurement each measurement is the wind speed coming to the rotor, the rotational speed of the rotor, the temperature, the pressure , the voltages out of the rotor and the current out of the generator which connected to the rotor and in this two tables the values was taken from result

Table 4.1 Values for first model three blades Savonius turbine.

V Velocity m/s	N Rotation speed rpm	V Voltage V	I Current A	Pa Wind power W	Pe Electric power W	Cp Power coefficient	λ Tip speed ratio
2	20.0	2.00	0.025	3.570	0.050	0.0140	0.492
2.5	25.6	2.60	0.040	6.972	0.104	0.0149	0.505
3	31.3	3.17	0.060	12.048	0.190	0.0158	0.514
3.5	37.0	4.70	0.077	19.131	0.360	0.0188	0.520
4	43.2	5.70	0.090	28.557	0.513	0.0180	0.532
4.5	49.4	6.40	0.100	40.661	0.640	0.0157	0.540
5	56.0	7.00	0.110	55.776	0.770	0.0138	0.551
5.5	63.0	7.50	0.120	74.238	0.900	0.0121	0.564
6	70.7	8.10	0.130	96.381	1.053	0.0109	0.580
6.5	79.8	8.67	0.143	122.539	1.236	0.0101	0.604
7	88.7	9.20	0.153	153.049	1.405	0.0092	0.624
7.5	96.0	9.67	0.158	188.243	1.524	0.0081	0.630
8	103.7	9.93	0.163	228.458	1.616	0.0071	0.638
8.5	111.8	10.24	0.168	274.026	1.717	0.0063	0.648
9	121.0	10.67	0.175	325.284	1.870	0.0057	0.662
9.5	128.8	11.07	0.186	382.566	2.058	0.0054	0.667
10	137.5	11.63	0.197	446.206	2.288	0.0051	0.677
10.5	146.7	12.47	0.213	516.540	2.660	0.0051	0.687

Table 4.2 Values for second model four blades Savonius turbine.

V Velocity m/s	N Rotation speed rpm	V Voltage V	I Current A	Pa Wind power W	Pe Electric power W	Cp Power coefficient	λ Tip speed ratio
2	20.0	2.00	0.025	3.380	0.050	0.0148	0.466
2.5	25.6	2.60	0.040	6.601	0.104	0.0158	0.477
3	31.2	3.13	0.060	11.407	0.188	0.0165	0.484
3.5	37.5	4.60	0.073	18.113	0.337	0.0186	0.499
4	43.0	5.60	0.090	27.038	0.504	0.0186	0.501
4.5	49.9	6.50	0.100	38.498	0.650	0.0169	0.517
5	56.5	7.00	0.110	52.809	0.770	0.0146	0.527
5.5	63.5	7.50	0.120	70.289	0.900	0.0128	0.538
6	70.5	8.10	0.130	91.254	1.053	0.0115	0.548
6.5	78.7	8.63	0.141	116.021	1.220	0.0105	0.564
7	86.5	9.10	0.151	144.908	1.377	0.0095	0.576
7.5	94.0	9.53	0.156	178.230	1.490	0.0084	0.584
8	101.9	9.87	0.161	216.305	1.592	0.0074	0.593
8.5	109.7	10.12	0.166	259.450	1.683	0.0065	0.601
9	119.0	10.58	0.173	307.981	1.827	0.0059	0.616
9.5	126.5	10.93	0.183	362.216	2.001	0.0055	0.621
10	135.0	11.47	0.193	422.471	2.217	0.0052	0.629
10.5	143.3	12.13	0.207	489.063	2.508	0.0051	0.636

R^2 in the graphs is the Pearson Linear Correlation Coefficient. This coefficient shows the correlation between the values in each category and this correlation between [1,1] more than 0.75 is a strong proportional correlation.

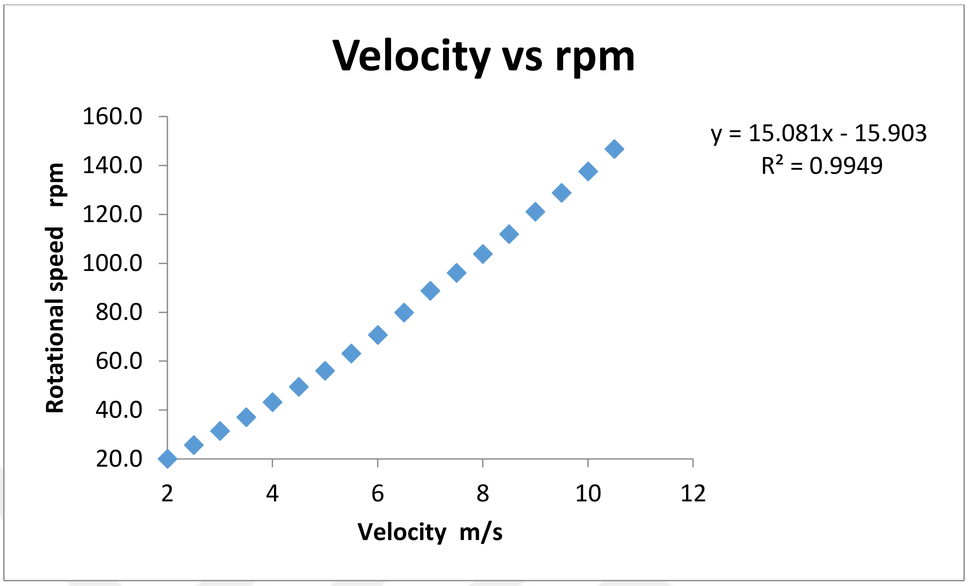

Figure 4.1 Relation between wind velocity and rotational speed of three blades rotor

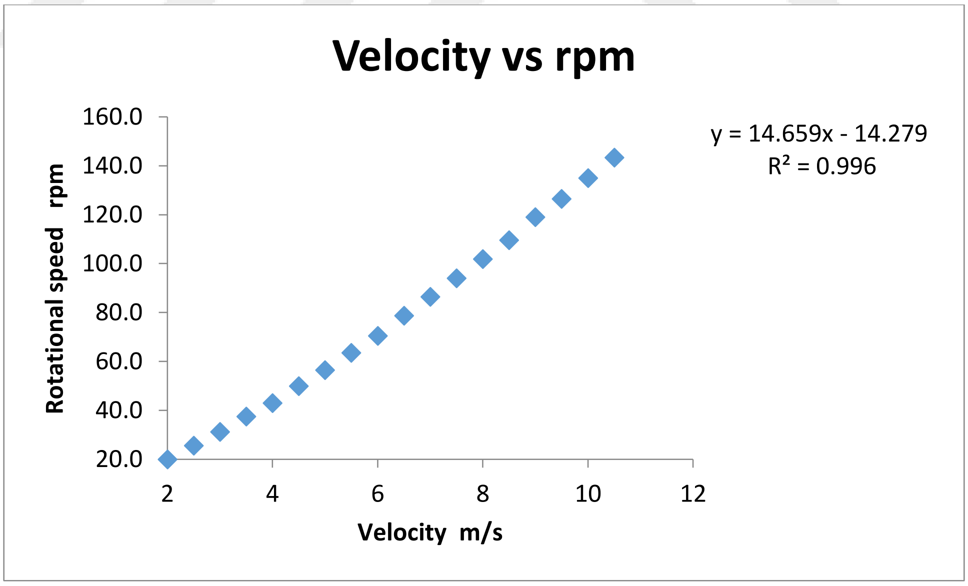

Figure 4.2 Relation between velocity of the wind and rotational speed of four blades rotor

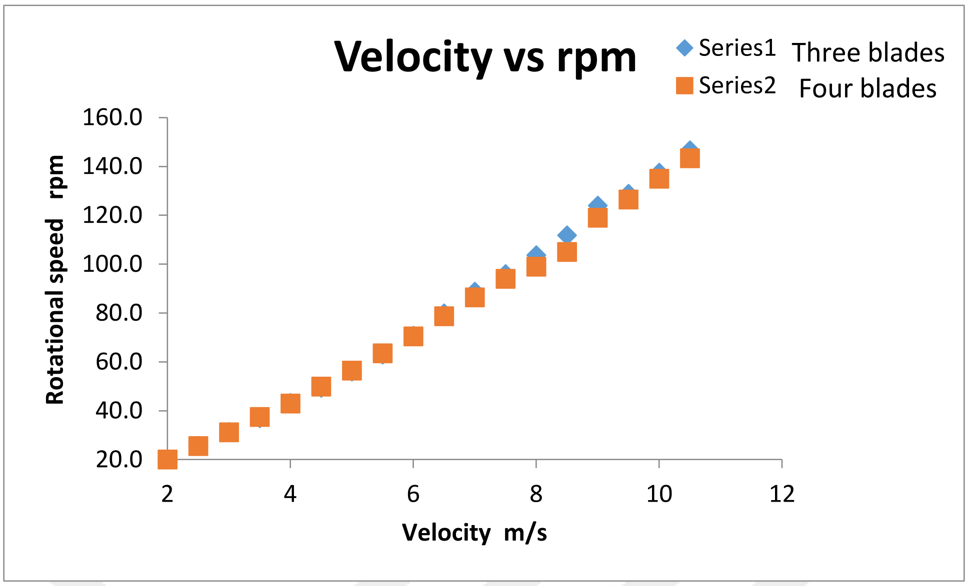

Figure 4.3 Relation between wind velocity and rotational speed of three and four blades rotor

The graph shows in Fig.4.1 and 4.2 and 4.3 the relation between the wind speed and the rotational speed in the two models. The wind speed ranged from 0 to 10.5 while the rotational speed differed in the two models. The three-blade model gave the highest rotation value Turbine 146.7 while the four-blade turbine has the highest rotation value of 143.3 due to the higher negative torque value in the four-blade turbine, which slows down the rotation of the turbine.

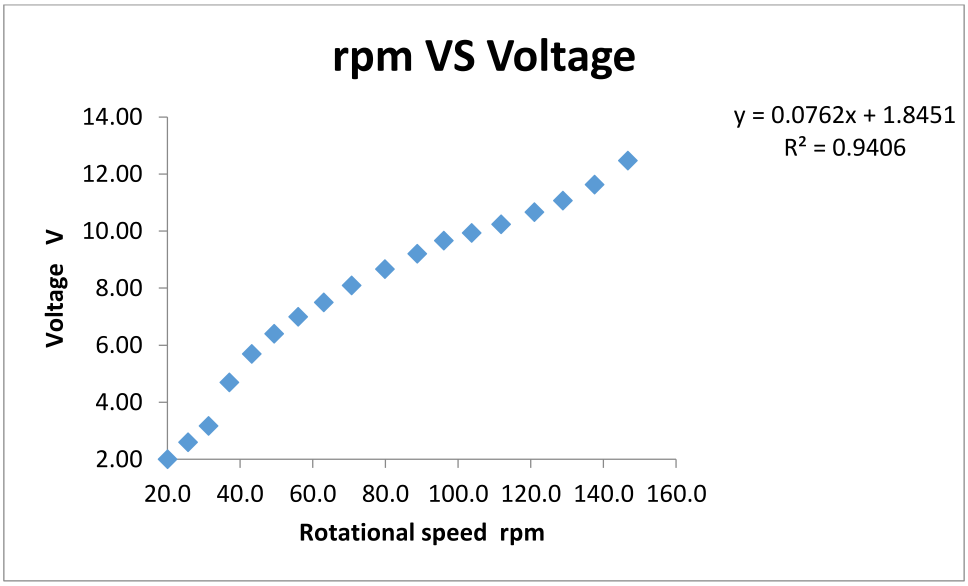

Figure 4.4 Relation between rotation of speed and voltage of three blades rotor

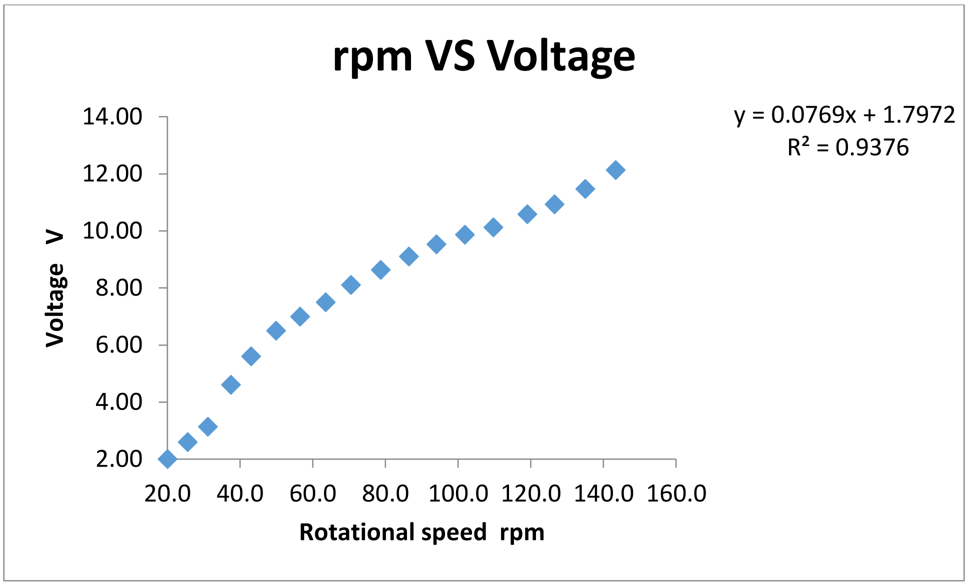

Figure 4.5 Relation between rotation of speed and voltage of four blades rotor.

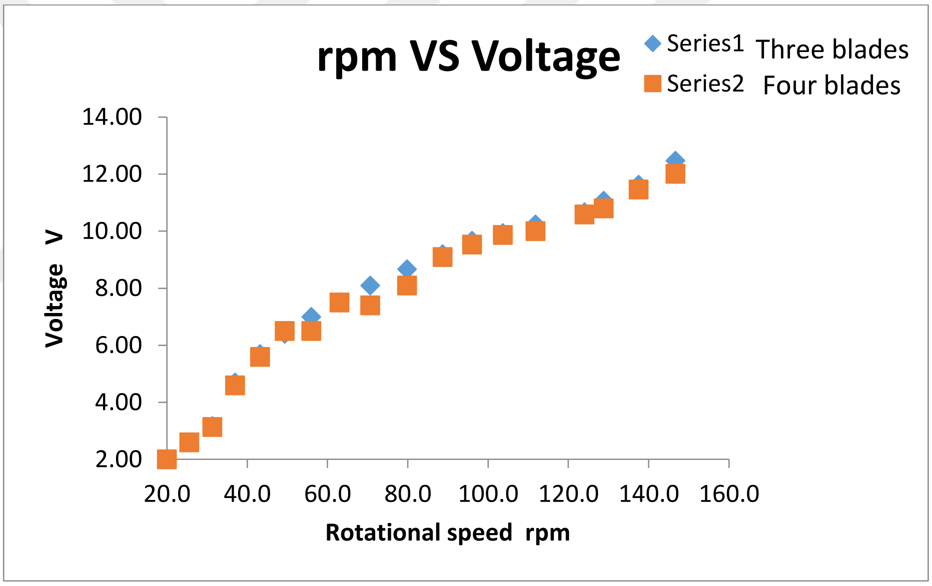

Figure 4.6 Relation between rotation of speed and voltage of three and four blades rotor.

The graphs show the relation between the rotational speed and the voltage generated by the generator. The graph show that in the three blades turbine, when the velocity was 146.7 the voltage was (12.5v). For the four-blade turbine, the highest value was (12.1) volts in rotational speed (143.3 rpm). The voltage in the turbine with three blades higher because it has the highest value of rotational speed.

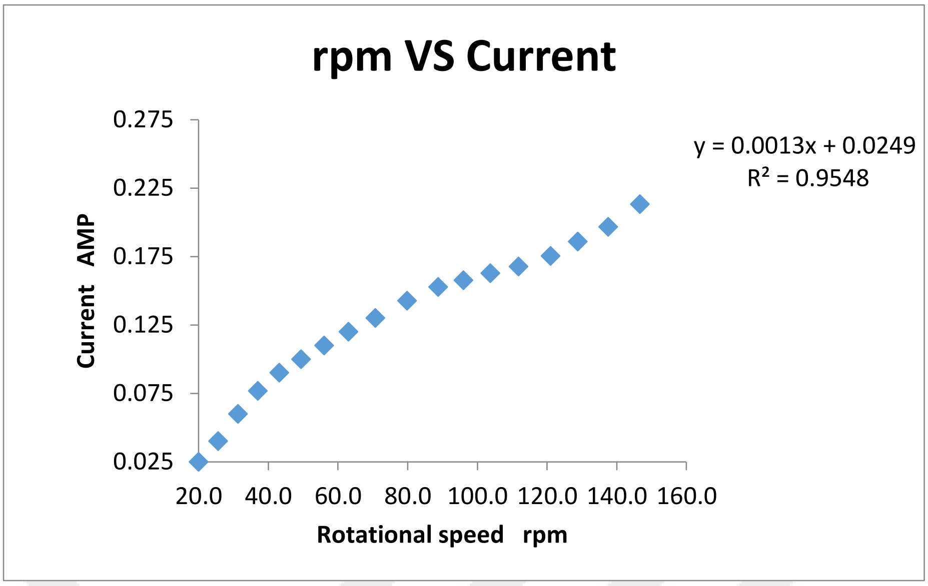

Figure 4.7 Relation between rotation speed of rotor and current of three blade rotor

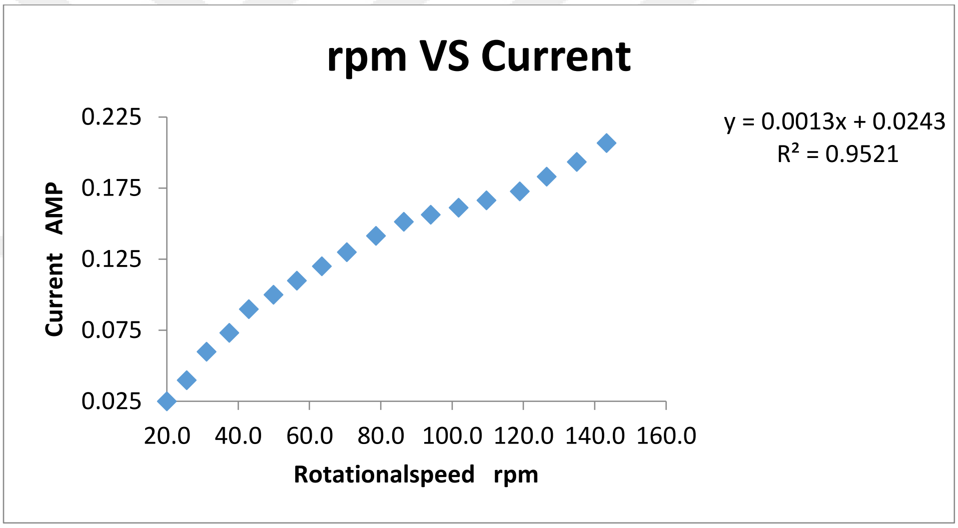

Figure 4.8 Relation between rotation speed of rotor and current of four blade rotor

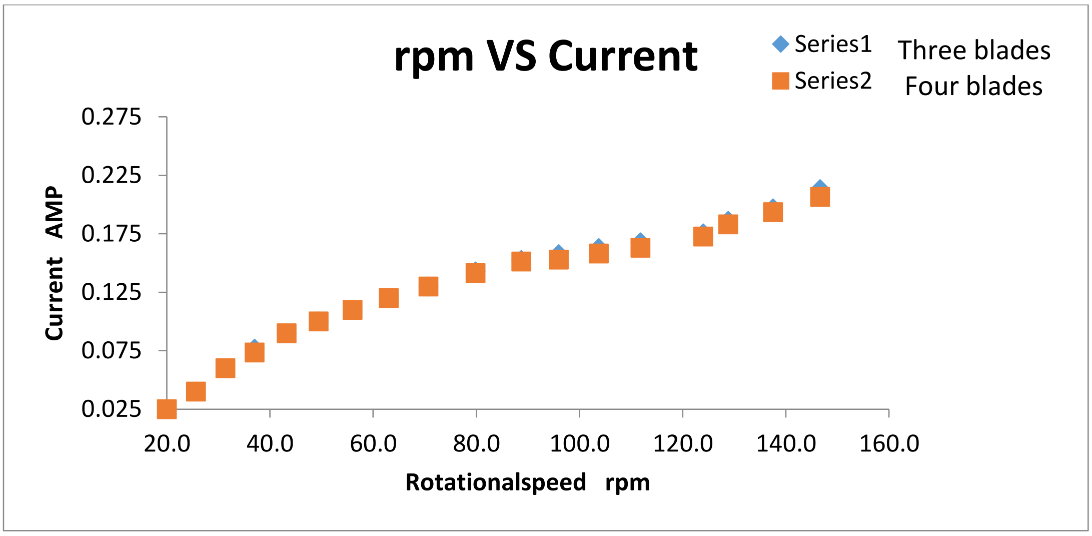

Figure 4.9 Relation between rotation speed of rotor and current of three and four blade rotor

The graph shows the relation between the velocity and the electric current generated by the electric generator placed on the rotors shaft. The figure shows that the top of the current in the three-blade turbine (0.213A) while the upper value Of the turbine in the four blades (0.207A) and it is clear that the geometry on the shape of the turbine with three blades better than four .

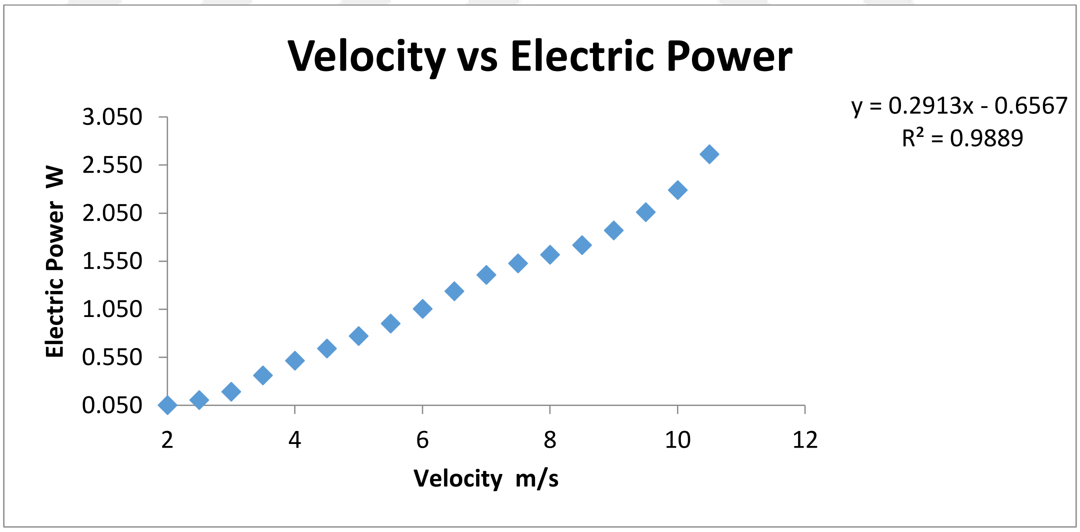

Figure 4.10 Relation between wind velocity and electrical power of three blades rotor.

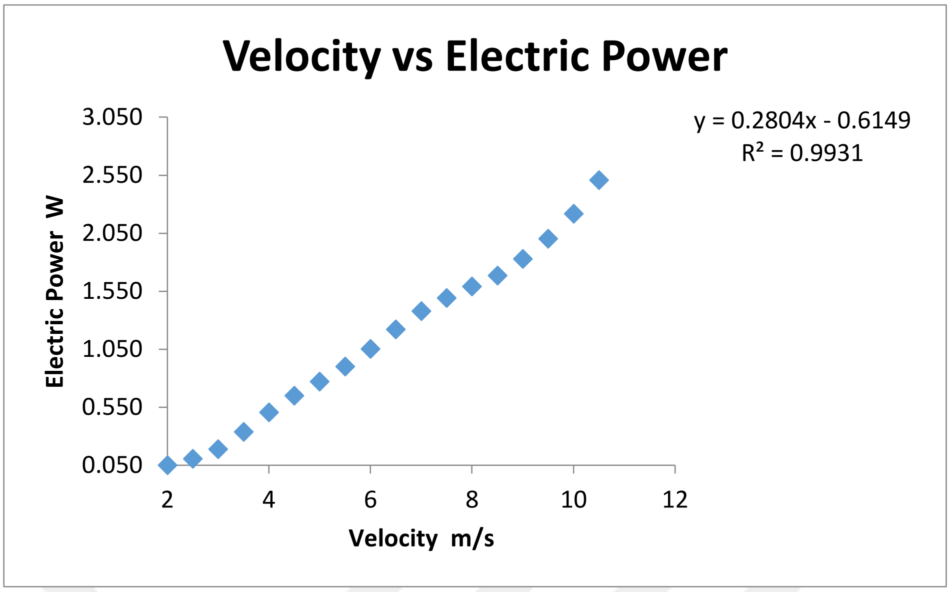

Figure 4.11 Relation between wind speed and electrical power of four blades rotor.

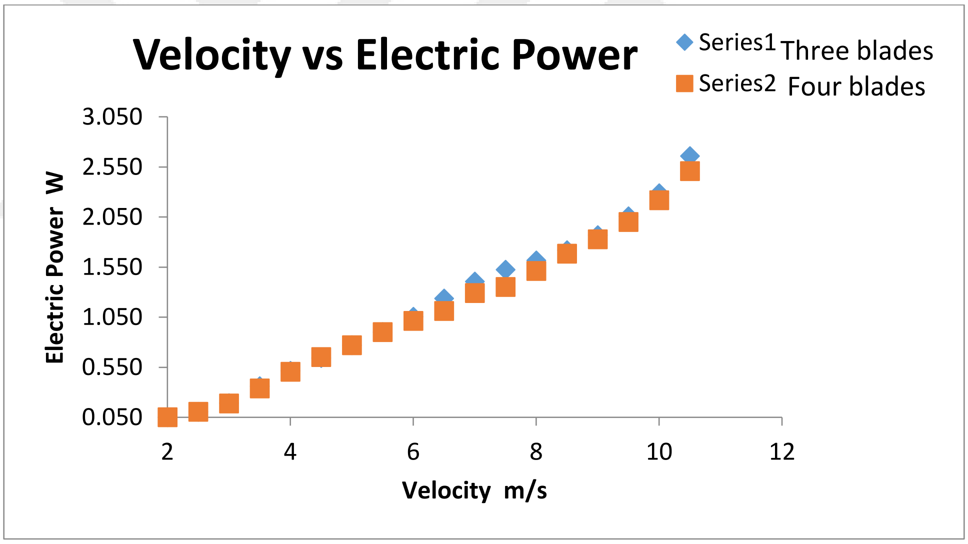

Figure 4.12 Relation between wind speed and electrical power of four blades rotor.

This graph is the relation between wind velocity and electric power which is determined by the equation. (3.3)

The highest value of electricity is (2.66W) for the three-blade turbine, while the four-blade turbine shows the highest value (2.508W) because the turbine performance in the three blades is better than the four blades.

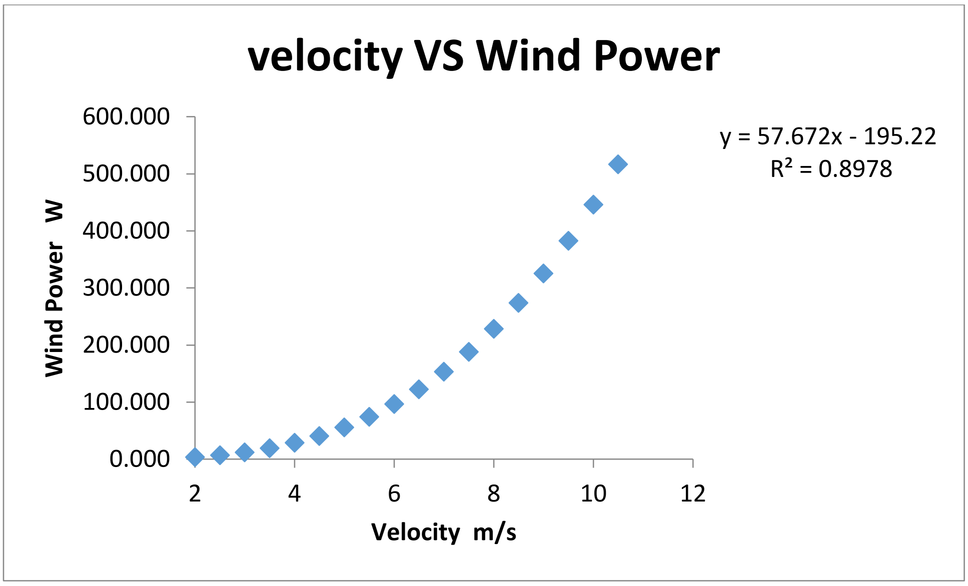

Figure 4.13 Relation between wind velocity and wind power of three blades rotor.

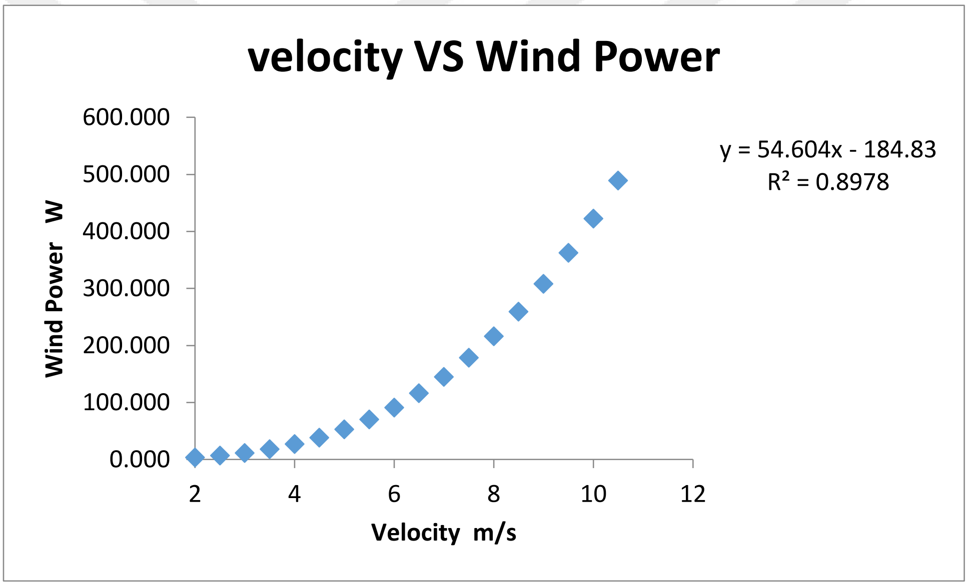

Figure 4.14 Relation between wind velocity and wind power of four blades rotor.

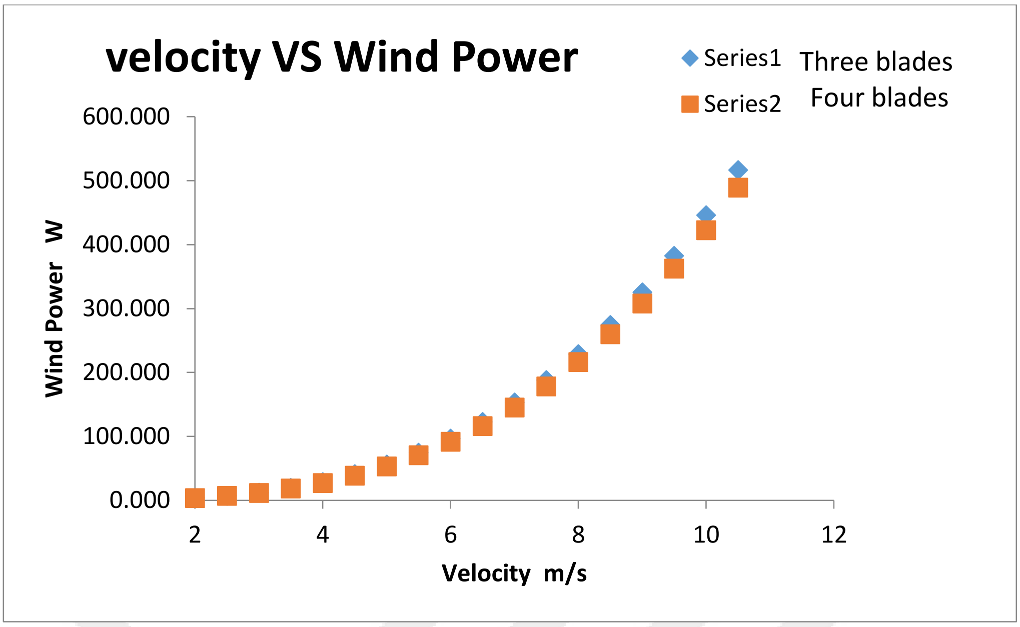

Figure 4.15 Relation between wind velocity and wind power of four blades rotor.

The graph shows the relation between the wind speed and the wind power in equation (2). From the graph it is clear that the high wind speed gives wind power (516.5W) in three-blade turbine and in four-blade turbine the value of the upper wind power is (498W). This is because turbines geometry is better in three blades turbine.

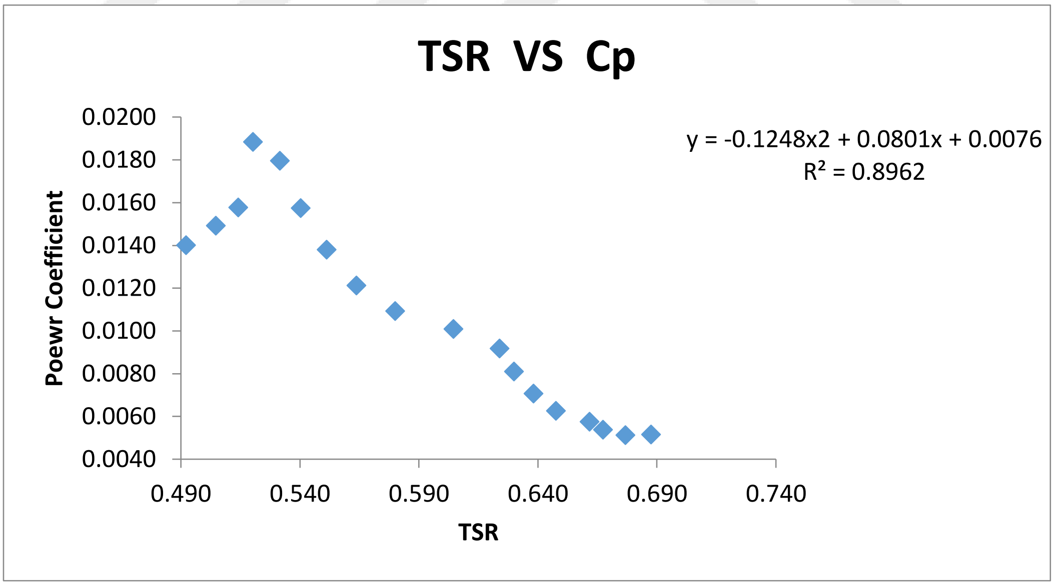

Figure 4.16 Relation between tip speed ratio and power coefficient of three blades rotor.

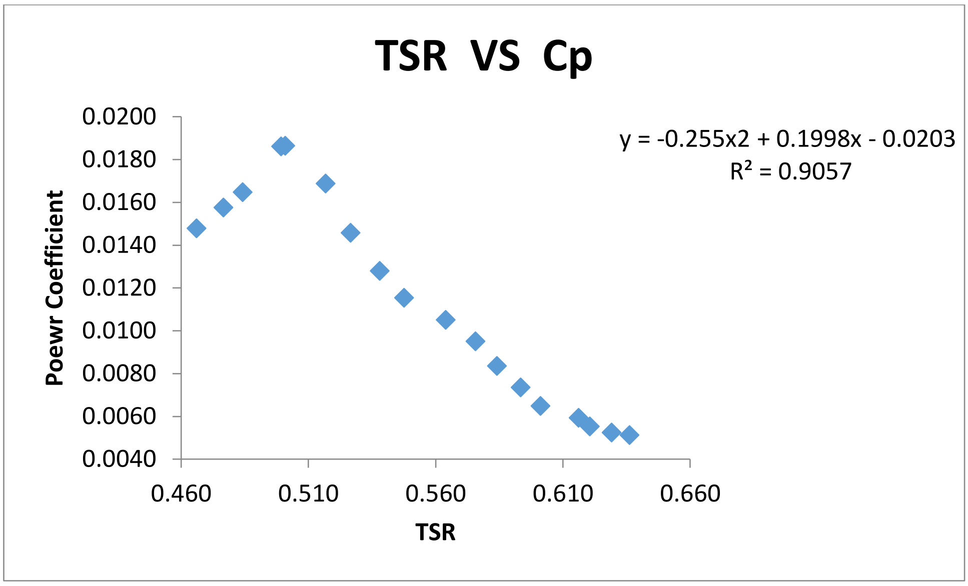

Figure 4.17 Relation between tip speed ratio and power coefficient of four blades rotor.

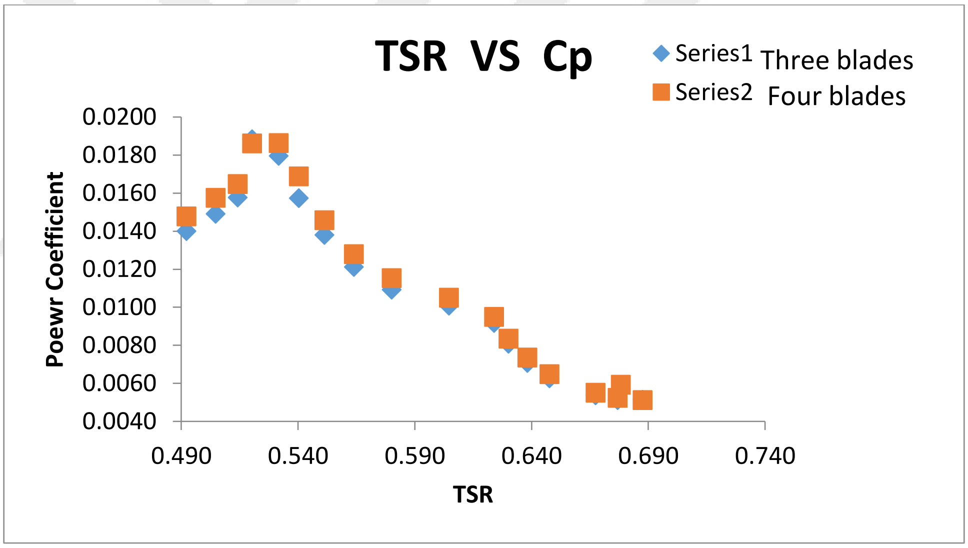

Figure 4.18 Relation between tip speed ratio and power coefficient of four blades rotor.

The graph shows the tip speed ratio calculated from the equation (6) and the efficiency coefficient calculated from the equation (4). as shown in the graph in the model of the three blades turbine that the highest value of efficiency coefficient (0.0188) is given by tip speed ratio (0.52) while in the four blades turbine the highest efficiency coefficient value (0.0186) is given by tip speed ratio (0.5).

For this reason, the three-blade turbine has a form geometry capable to giving energy better than a four-blade turbine.

CHAPTER 5

CONCLUSION

Rotors were manfutured from empty oil barrels . The two models differed in the number of blades and similar in length, thickness, material of the rotors and the electrical generator. this research to determine the bitter number of blades to get more efficiency. Experiments were mesured in the climatic conditions of Gaziantep (wind speed, pressure and temperature) for four months. The measurements were recorded every five minutes for 12 hours on each working day. Measurements are wind speed, rotational speed of the rotor , voltage value and current values for both models. the first model contain 3 blades and the angle between two consecutive blades is 120 degrees, and the second model with four blades separate the blades angle 90 degrees.

1. Turbine with three blades up to 146.7 rpm at 10.5m/s while the four blades turbine up to 143.3 rpm for the same velocity of the wind.
2. The highest value of power coefficient in three blades rotor is (0.0188) at tip speed ratio (0.520),and the four blades rotors have up value of power coefficien (0.0186) at the tip speed ratio of (0.499), thus the efficiency in the three blades turbinre is more than four blades one.
3. By comparing the results obtained with other results of thesis to the same specification of the rotor with the difference in the number of blades with 2 blades and 5 blades rotor, it is clear that the highest speed of rotation of the router is when the rotor with two blades, where the speed of rotation to 150 rpm in the same condition while the 5 blades 140rpm and here we find that the two blade rotor with the highest efficiency of savonius rotor
4. The HAWT are more efficient than the VAWT in terms of productivity and electricity output, but VAWT are low cost of production

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