The Effects of Blades Number, Blade Thickness, Blade Tip Angle, and Twist Angle on the Performance of the Rotor Wind Turbines

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Abstract

The paper gives an experimental study on the performance on the wind turbine rotors with several numbers of blades as well as twist angle. The main goal of this study is to demonstrate the effect blades number, tip angles as well as the twist angle of the blades on the power coefficient (Cp) of the rotor. Moreover, this result represents a simple evaluation about the range of depending power coefficient on the average wind speed.

Also, this paper studies the performance of wind turbines which are tested by carrying out 2-dimensional dynamic using ANSYS-Fluent.

Key words: Blades Number, Tip angle, Twist angle, Wind turbines

1. Introduction

Wind energy represents one of the main resources for generating electricity. This is because it does not cause any pollution. Therefore, the scientists focus greatly on producing economical wind turbines in order to decrease the cost of power generation. Moreover, most of the previous techniques of developing wind turbines considered the highest efficiency of these turbines is the most important property of their designing characteristics in addition to achieve overall good efficiency[1, 2]. The efficiency of the wind turbines depends essentially on the blades of their rotors. In fact, the twist of the blades as well as the blade tip angle play an important role in extracting optimal power from wind power [3, 4]. Also, the tip speed ratio has to be selected accurately in designing wind turbine blade. On the other hand, tip speed ratio depends greatly on the profile type of the rotor in addition to the number of blades [5]. In practice, the observed kinetic energy, which can be changed to mechanical energy, is proportional with the number of blades [6]. This means increasing the number of the blades increases the efficiency of the turbine. Nevertheless, when blades number becomes so high, the space between them decreases then a back pressure can be generated [6]. This pressure reduces the efficiency of the turbine [6]. In the last decades, numerous studies focus greatly in increasing the scale of wind turbines, which have a very narrow range of tip speed ratio (TSR). One of these studies demonstrates that the Cp of vertical axis wind turbine (VAWT) can be 0.30 in the experiment with cross flow runner [7]. This value is considered the highest between the types of VAWT. This is because cross flow turbine involves a number of circular blades. This helps air effectively in passing through runner twice, which increases the efficiency [8, 9].

This paper will discuss the performance of various profile types of wind turbine with various numbers of blades. The main aim of this paper is to implement experimental study to demonstrate the influence of several parameters like number of blades, blade thickness, blade tip angle, and twist angle of the blades tip on the response of wind turbines.

2. Wind Turbine

The development and research focused mainly on wind turbines with 3 blades during the last few decades. On the other side, the 2-bladed turbines remain under study and development until the 1970's and 1980's. After that, the research effort on the 2-bladed turbines had been decreased obviously especially during recent years. This is because the 2-bladed turbines have more disadvantages like higher noise emissions, the distracting visual influences as well as the bad dynamic performance.

One of the main equations which are necessary in this field is Continuity equation [10]. This formula is used generally in Computational Fluid Dynamics. It is given below [10]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

The formula of Navier-Stokes for 2 Dimensions [10]:

For horizontal axis (X-Axis):

$$\rho\left(\frac{\partial \mathrm{u}}{\partial \mathrm{t}} + \mathrm{u}\frac{\partial u}{\partial x} + \mathrm{v}\frac{\partial u}{\partial y}\right) + \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + v\frac{\partial^2 u}{\partial y^2}\right)$$

For vertical axis (Y-Axis):

$$\rho\left(\frac{\partial \mathrm{v}}{\partial \mathrm{t}} + \mathrm{u}\frac{\partial v}{\partial x} + \mathrm{v}\frac{\partial v}{\partial y}\right) + \rho g_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial y^2} + v\frac{\partial^2 v}{\partial y^2}\right)$$

There are two main factors used in calculating wind turbine responses which are moment coefficient (Cm) as well as power coefficient (Cp). The value of Cm is defined as follows [7]:

$$\mathrm{Cm} = \frac{M}{0.25\rho v_\infty^2 D_1 S'}$$

M: positive moment of turbine movement

V: wind speed

D: blades diameter of wind turbine

In addition, Cp is given in the following equation [7]:

$$\mathrm{Cp} = \lambda Cm$$

3. Wind Turbine Performance Parameters

The performance of a wind turbine can be enhanced by adopting one of the following methods:

Number of blades one of the factors which have studied carefully during design any wind turbine is the number of blades. Moreover, Punit and Franz confirm the number change of the blades effects on the relative flow at the runner exit [14]. This influence varies the frictional losses of the turbine depending on blade thickness, blade tip angle and blade twist angle. Twist angle of blade is similar in concept to axial deformation. It depends mainly on tip speed ratio (λ) of the wind turbine. The tip speed ratio λ is explained as the ratio between angular velocity of the wind turbine rotor and the linear wind speed at the tip of the blades [16]. In general, twist angle is measured in radian.

4. Experimental Results

This part will highlight on three main aspects of the research. The first aspect is the information on the wind turbines, which had been tested during the study. This aspect is very important because there are several categories of wind turbines. In addition, these categories have main differences between each other in performance, advantages, disadvantages, and efficiency. The second aspect is the

Scenarios which have been tested to determine the performance curves of wind turbines. This aspect gives a clear idea about experimental result and how they have been measured.

4.1 Information of the Tested Wind Turbines

In this paper, there are two wind turbines have been tested. The modification of these two turbines is similar NACA 44. However, the size of them is different so the first one (type A) is 1 KW while the second one (type B) is 2 KW. Additionally, the properties of these two turbines such as the length, maximum chord and so on will be different also because they do not have the same size. The information of the two turbines is given tables 1 and 2 below.

Table 1: the information of the wind turbine type a

Type a (Blades for 2kW wind turbine)	
Length	1500mm
Maximum chord	194mm
Chord at the blade tip	139mm
Blade twist	22^0

Table 2: the information of the wind turbine type b

Type **b (Blades for 1kW wind turbine)**	
Length	1150 mm
Maximum chord	180 mm
Chord at the blade tip	95 mm
Blade twist	17^0

Furthermore, the number of the blades of the turbines is varied during experimental study. Clearly, The first type (type a,) has been checked in three configurations: 2, 3 and 6 blades of rotor. However, wind turbine type b is tested only with 3 blades of rotor. In addition, the cross section of these two generators is same however the type of windings is changed.

4.2 Wind Turbine Power Coefficient: Various Scenarios

Before implementing any scenario, there are several parameters which have to be calculated practically. Firstly, cut in speed is measured for each turbine. This speed is measured by testing the wind turbine at a specific tip angle for blades without load. This test is performed with a range of wind speeds with a small period between these speeds for air flow. Moreover, the power curve of the wind turbine is calculated by torque change as shown in Figure 1 below.

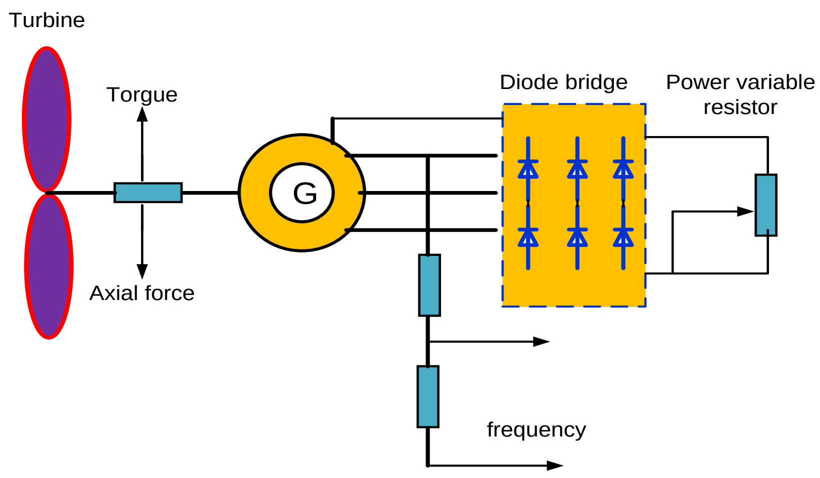

Fig. 1: Simple block diagram of wind power generating unit.

In clear, the torque and the power of the turbine are varied through changing power resistor from the maximum value to the minimum. The torque is proportional inversely with this resistor. As a result, the torque reaches the maximum value with a minimum power resistor. There are three magnitudes of wind speeds which are 6,5m/s, 8,5m/s and 10,5 m/s. These values are considered reference wind speeds (Vref). These speeds are applied in all tests of this paper with various configurations of small wind turbines to demonstrate their power curves. After that, the two turbines (type A and type B) will be tested in different configurations and blades as given below. For blades type A, the length of rotor diameter is 3,2m. While for blades type B, it is 2,6m.

4.3 Measurement method

To calculate the cut in speed of the turbine, it is tested without load at a specific tip angle. For adjusting wind speed through the tunnel, air flow is increased gradually in several steps will lagging time between them. By this mechanism, cut in wind speed of the turbine is calculated. Experimental results demonstrate that the cut in speed of the turbine is 100 turns/min. In addition, variable torque helps clearly in drawing power curve as shown in figure 1.In the beginning, the value of the power resistor is increased to the maximum for keeping wind speed at the required speed. After that, load resistor is decreased gradually in order to increasing generated power as well as torque of synchronous generator up to maximum values. At the same time, the information of the wind turbine such as wind speeds, torques as well as rotational speeds of the rotor are recorded. There are three wind speeds (Vref) are considered as references for all configurations of power curves. These speeds are 6m/s, 8m/s and 10 m/s. Those velocities are kept same in all applied experiments. In fact, these wind speeds help largely in drawing power curves of small wind turbines.

5. Power Curves of Wind Turbine

5.1 Power Curves of Wind Turbine Type A blades

Wind turbine type A had been checked in three case studies when blades of rotor 2, 3 and 6.Wind turbine is tested in standalone battery storage power source as well as connecting station directly to the grid. The values of power coefficients (Cp) are found with respect to tip speed ratio (λ). Equations (1) and (2) below demonstrate this relationship between the generated power and tip speed ratio [3]:

$$Cp = \frac{P}{\pi \frac{\rho}{2} \cdot v^3 \cdot R^2} \qquad \text{--------------------------------(1)}$$

$$\lambda = \frac{2 \cdot \pi \cdot R \cdot n}{v} \qquad \text{------------------------------(2)}$$

Where.

P: calculated mechanical power

P: the air of density

V: calculated airspeed

Λ: tip speed ratio

D: the diameter of rotor

R: the radius of rotor

In all experiments, it is impossible to adjust wind speed in tunnel at a specific magnitude exactly. The deviation of these speeds form correct values is about 0,5 m/s. consequently, a small correction is implemented to the calculated power by applying equation (3):

$$P = Pm \cdot \left(\frac{vref}{v} \right)^3 \quad - \qquad \text{----------------------------(3)}$$

Where:

Vref: reference wind speed,

Pm: calculated power

a) Power coefficient of 2 blades rotor

In general, the tip angle of the rotor blade is small in order to run at best situation. Consequently, the tip angle is changed for these three small values which are 00, 20, and 50.The test results are shown in figures 3, 4, and 5 below.

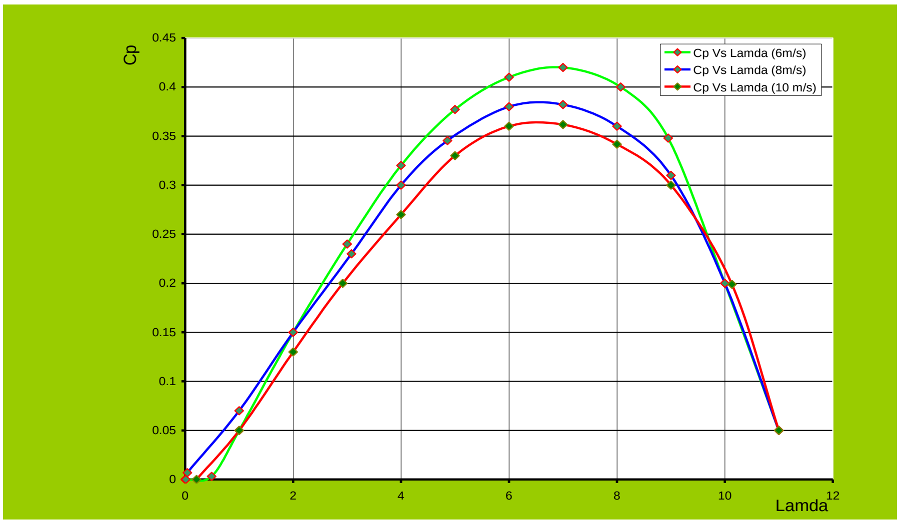

Fig. 3-Cp for 2 blades at 0^0

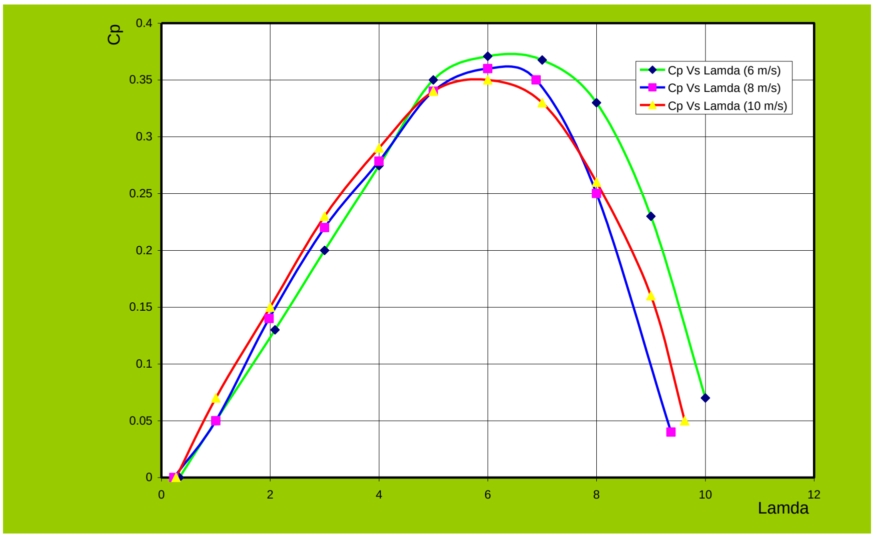

Fig 4-Cp for 2 blades 2^0

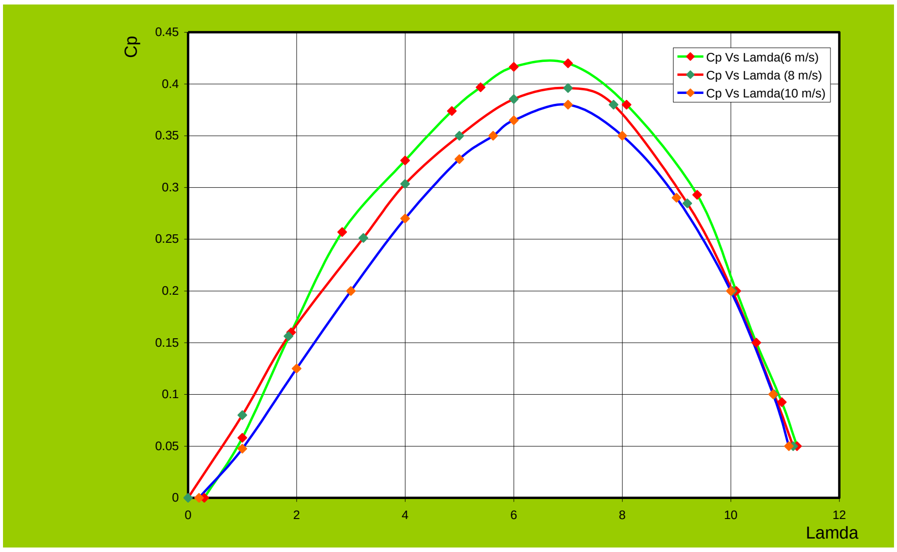

Fig 5: Cp for 2 blades 5^0

There are number of notes which can be obtained from above figures of the 2 blades rotor as shown below:

1. Increasing tip angle of the blades reduces the power coefficient.
2. There are several elements such as tip speed ratio (λ) and highest power are reducing with tip angle of the blades.
3. The influence of changing wind speed on the power coefficient is small at high speeds. While this effect becomes higher at low wind speeds.
4. The greatest extracted power and optimum efficiency is implemented at small tip angle.

Therefore, the best response for this type (type a) is occurred at low wind speeds and that useful for many places. In addition, the place of wind turbine installation and its average wind speeds plays an important role in selecting the tip angle of rotor. When average wind speed is high, tip angle of the rotor has to decrease then the power coefficient increases. Moreover, when average wind speed is low, the tip angle has to be improved in order to reducing the cut in speed of the turbine. Nevertheless, the power coefficient varies of these turbines (type a) is changing about 10% during rising wind speed from 6 m/s to 10m/s.

b) Power coefficient for 3 blades rotor

In this part, the wind turbine type a with same diameter as previous part had been used, however the blades of the rotor becomes three. Moreover, the same previous tip angles of the rotor had been tested. The curves of the power coefficient at these angles are shown in the figures 6, 7, and 8 below.

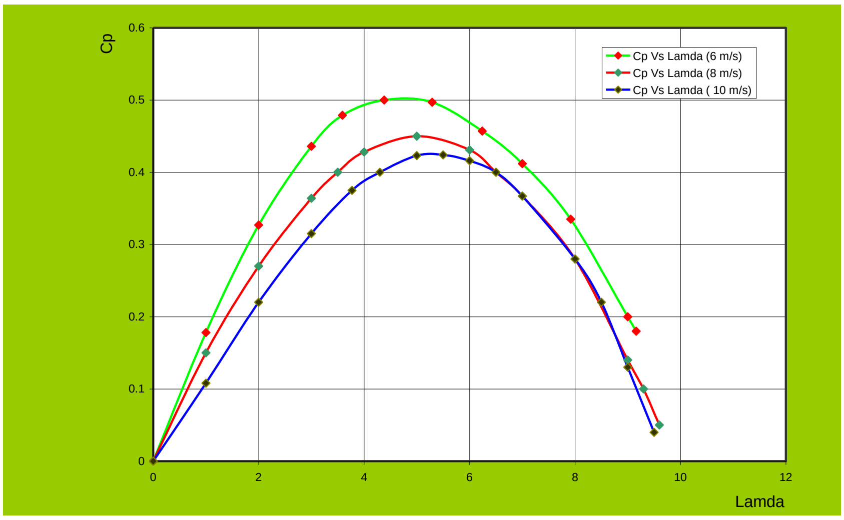

Fig.6: Cp for 3 blades 0^0

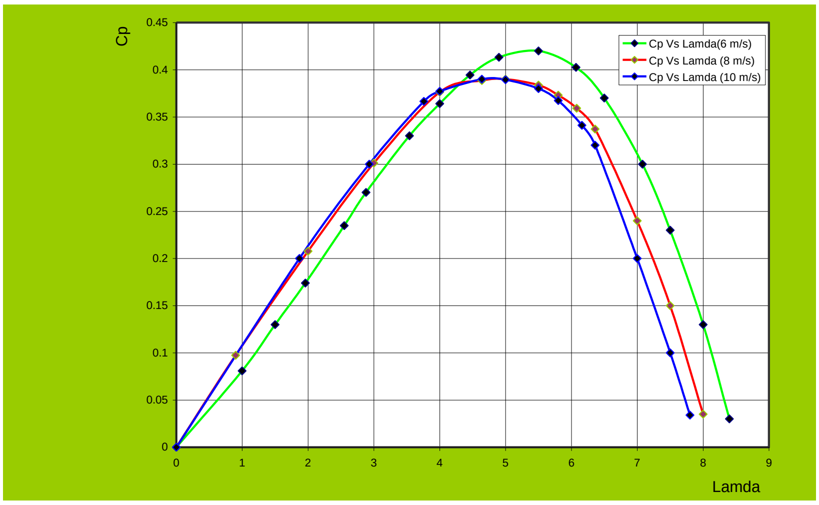

Fig. 7: Cp 3 blades 2^0

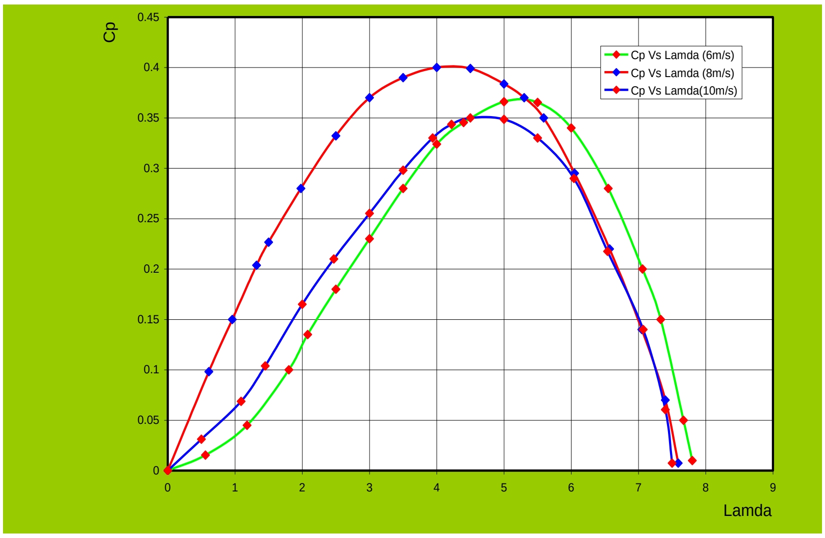

Fig 8: Cp 3 blades 5^0

The result demonstrates that power of the turbine with 3 blades is higher than the power of the turbine with 2 blades with same tip angles. This result is expected because 3 blades help more than 2 blades in extracting power from wind. On the other hand, tip speed ratio and λ in this situation are less than their peers for 2 blades.

c) Power coefficients for 6 blades rotor

In this case the number of the blades had been increased to six. The results of the power coefficients are given in figures 9, 10, 11, and 12.

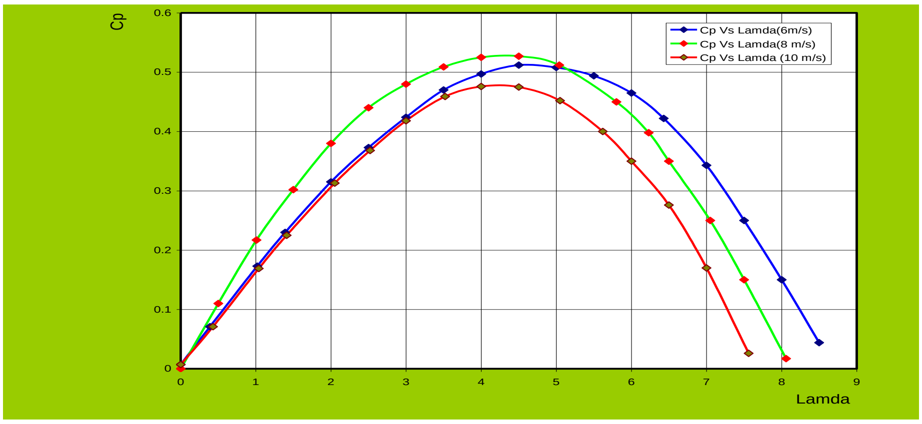

Fig. 9: Cp for 6 blades 0^0

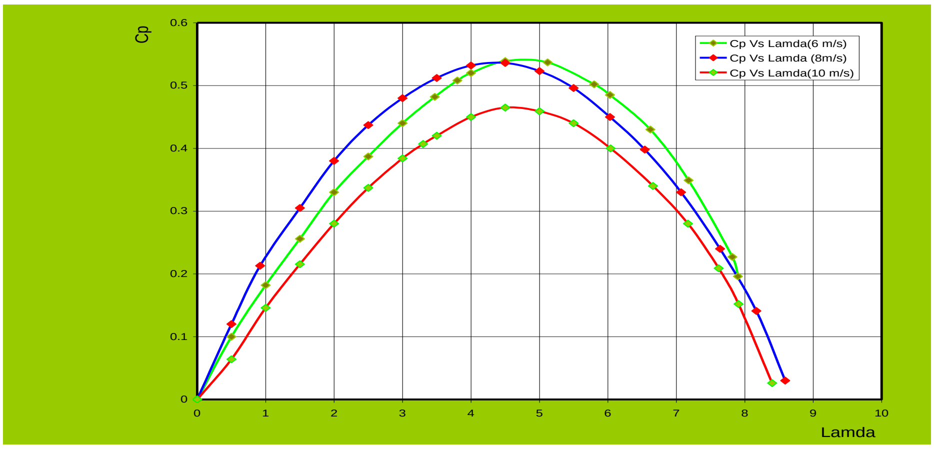

Fig. 10: Cp for 6 blades 20

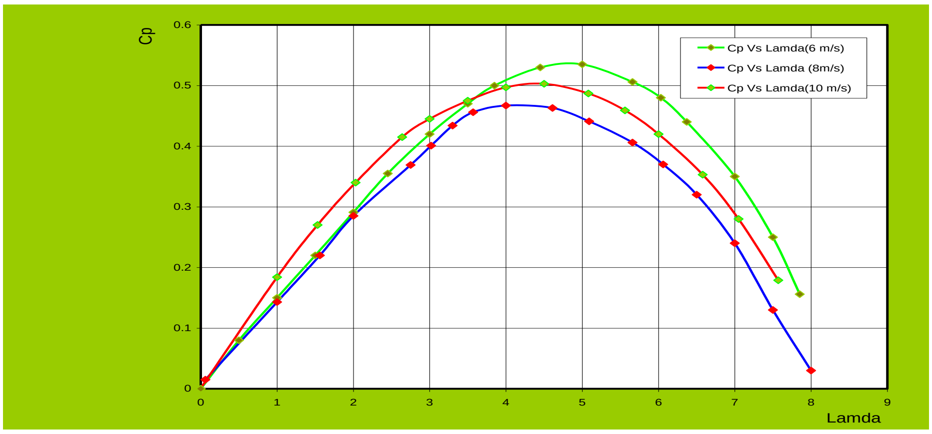

Fig. 11: Cp for 6 blades 50

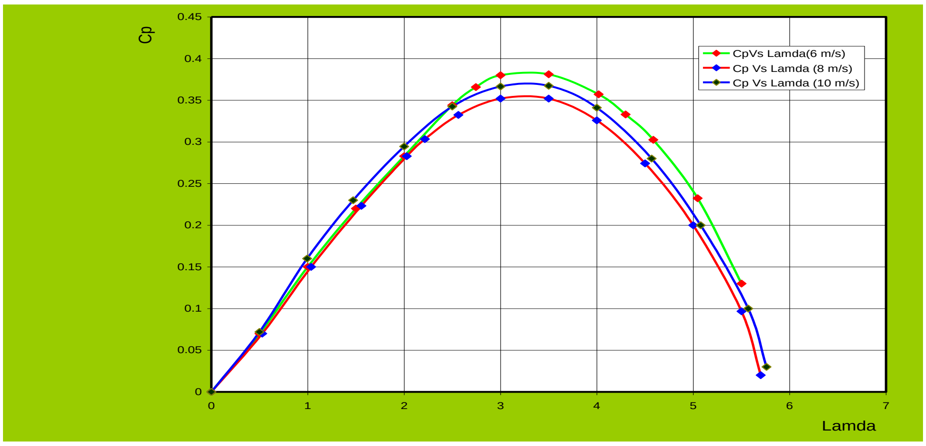

Fig. 12: Cp for 6 blades 10^0

In this case study, the power coefficients are better than previous two cases. In addition, the variation in power coefficient with changing tip angle of the blades from 00to 50is small. Also, this variation becomes bigger with low wind speeds.

d) Summary of wind turbine type A results

According to preceding study, it is clear that the number of the blades play an important role in changing the value of several main factors such as power coefficient (Cp), cut-in speed of the turbine and so on. As a result, designer depends mainly on these characteristics like power coefficient (Cp), and required cut-in speed of the turbine in selecting its number of the blades. Furthermore, average wind speed of location for installation represents one of the main factors in restricting number of blades. Figure 13 below demonstrates the variation of maximum power coefficient with respect to wind tip angle at different number of blades. Moreover, the decreasing of wind speed reduces the power coefficients directly. However, most of wind turbines become quicker with decreasing the number of blades [3]. Figure (14) demonstrates that tip speed radio, and λ decrease with increasing tip angle of the blades. In addition, α of the 2 blades turbine, when the speed equals to Cpmax and λ equals to λmax, is so lower than its peers of 3 or 6 blades rotor. With respect to 6 blades, λ max becomes slower. It is noticed that α equals to 80 for 2 blades rotor. Moreover, it is as quick as 6 blades one.

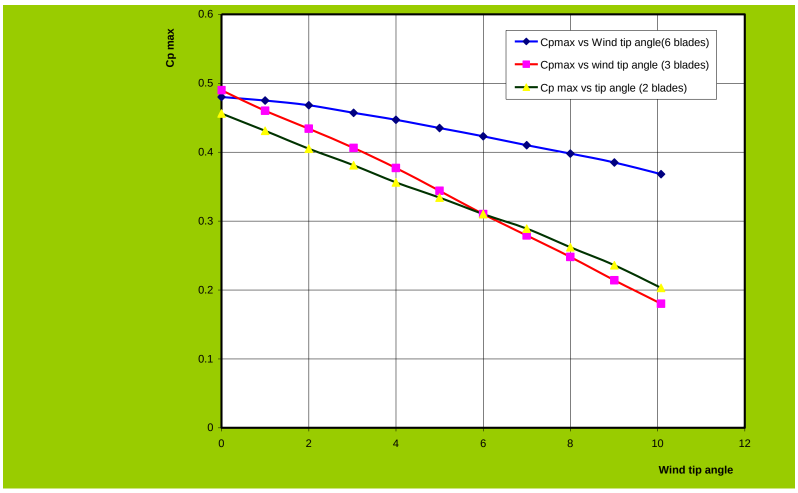

Fig. 13: Power coefficient vs. blade tip angle

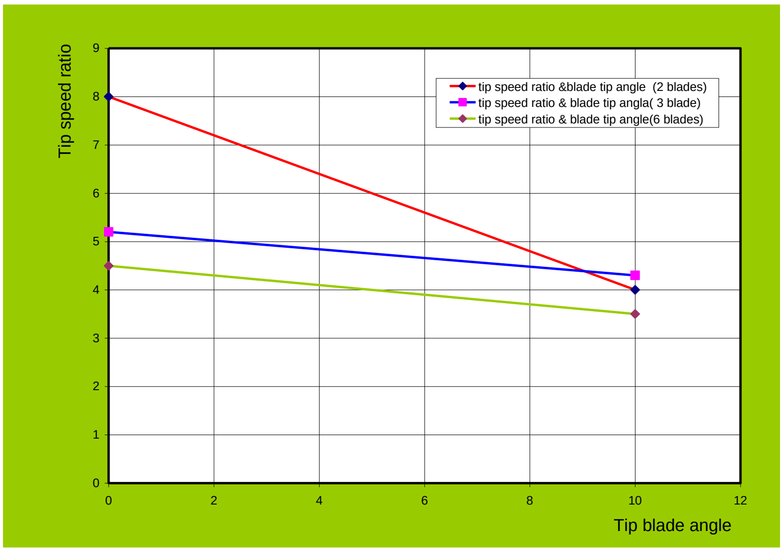

Fig. 14: Tip speed ratio vs tip blade angle

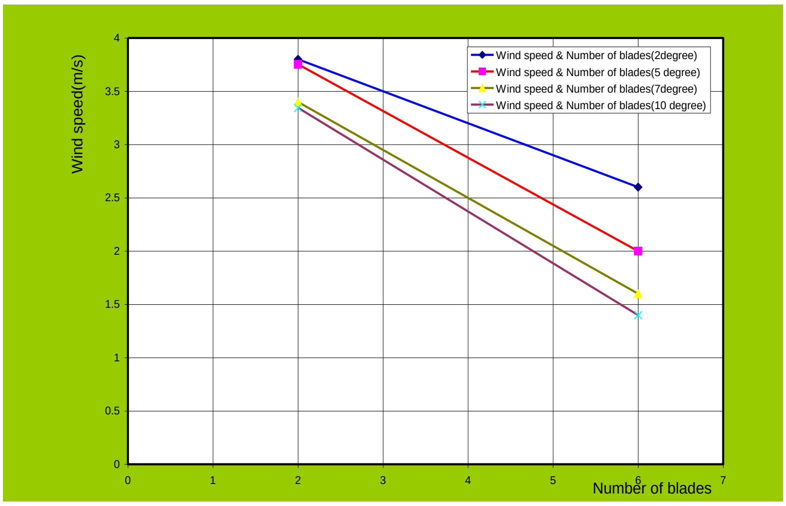

Fig.15: The difference in Cut-in wind speed between the configurations of type A with different blade number.

Cut-in speed represents one of the main features of the turbines. Figure (15) above demonstrates the change of cut-in wind speed with respect to the number of blades at different tip angle of blade, as well as α. In general, cut-in wind speed of the turbine is decreased with increasing the number of blades. However, cut-in speed decreases with boosting the tip angle of blades.

The average wind speed of the installation position plays a significant role in identifying blades number, blade tip angle as well as cut in wind of the turbine which should be installed. The variation of both cut in wind speed and power coefficient as compared with blade tip angle is similar. Both of them decrease with increasing blade tip angle.

5.2 Power Curves of Wind Turbine Type B

Wind turbine type b blades are really designed with optimum design principles as given in table 2 before [3]. Moreover, the configuration of rotor blades for turbine type b was checked with just 3 blades. The main goal of this study is to evaluate the influence of twist blade angle on wind turbine performances experimentally.

Power coefficient evaluation for type a as well as b represents an approximate estimation for the effect of blade twist angle on the response of these devices. The rotor blades of type b have highest power coefficient when the angle of blade tip equals to 70. The additional experiments have been measured when α equals to 100, 12 and 200.These results are demonstrated in Figures 16, 17, and 18 respectively .As known, the power coefficient is proportional directly with wind speed.

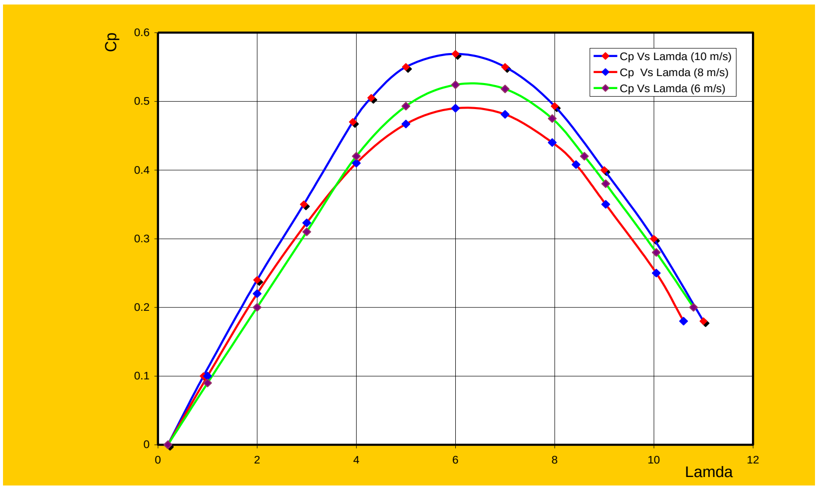

Fig. 16: Cp of rotor type b when α =7^0

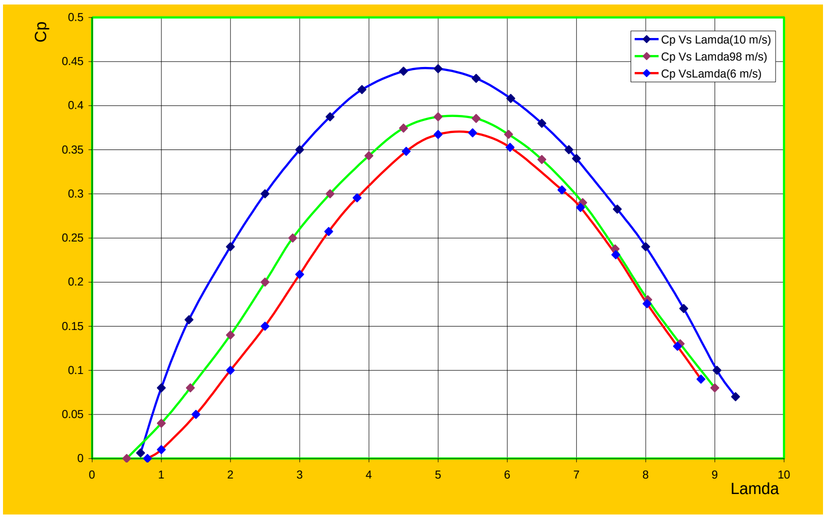

Fig. 17: Cp of rotor type b when α =10^0

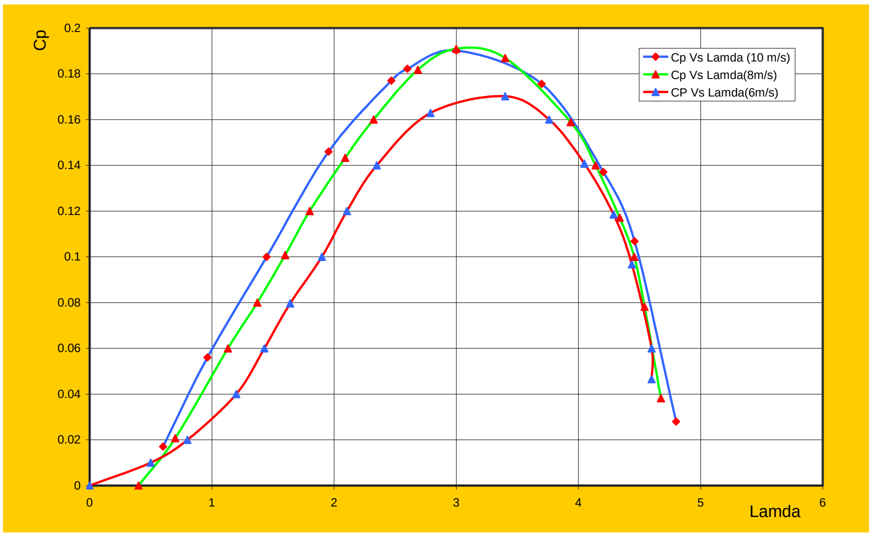

Fig. 18: Cp of rotor type B when $\alpha = 20^0$

According to the results above, wind turbines type b are more suitable for the high wind speeds. On the other hand, Figure (19) shows average power coefficient declines quickly with increasing tip angle of the blade.

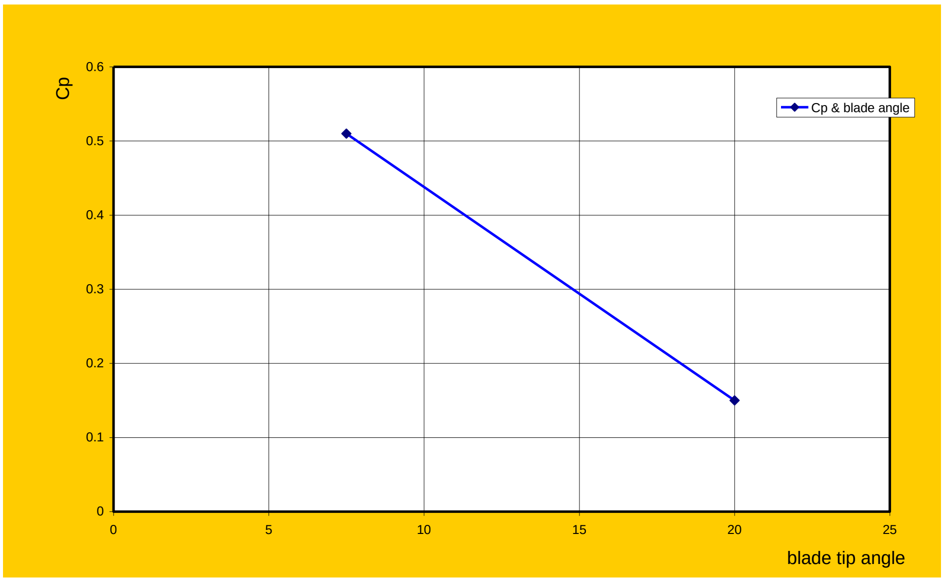

Fig. 19: Cp vs. blade tip angle

Similarly, tip speed ratio of these wind turbine types minimizes with rising tip angle of blades as shown in Figure 20 below.

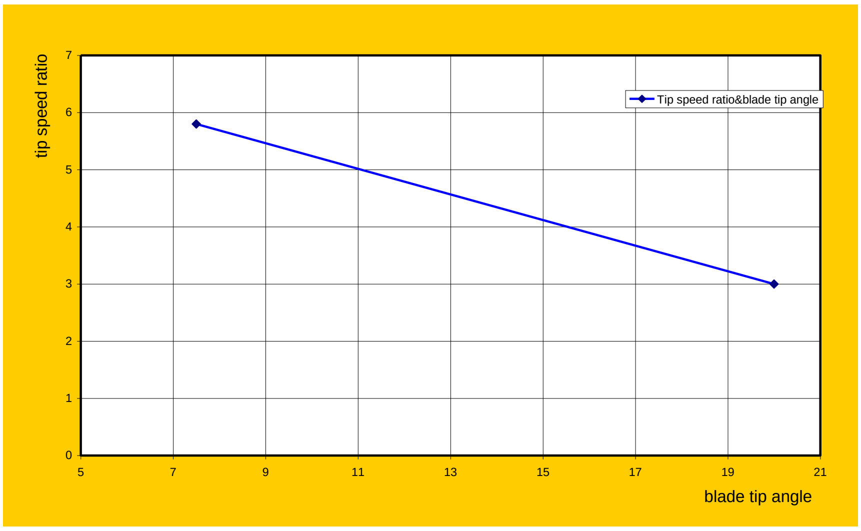

Fig. 20: Tip speed ratio vs. blade tip angle

During this study, the influence of the blade thickness on the power coefficient (Cp) has been highlighted.

This influence is studied at five different values of tip speed ratio (TSR). In clear, the blade thickness is varied from 2.5 mm to 10 mm, then to 15 mm and finally to 20 mm. changing blade thickness affects clearly on the magnitudes of both power coefficients (Cp) as well as TSR. Furthermore, power coefficient of the turbine is decreasing with growing the thickness of the blades. In clear, Maximum power coefficient (Cp) is obtained when the blade thickness equals to 20 mm. At this case, TSR is 0.2. Moreover, the highest value of power coefficient (Cp) is 0.499 which can be gotten at 20 mm blade thickness. The relationship between power coefficient (Cp) and TSR is shown in figures 21 and 22 below.

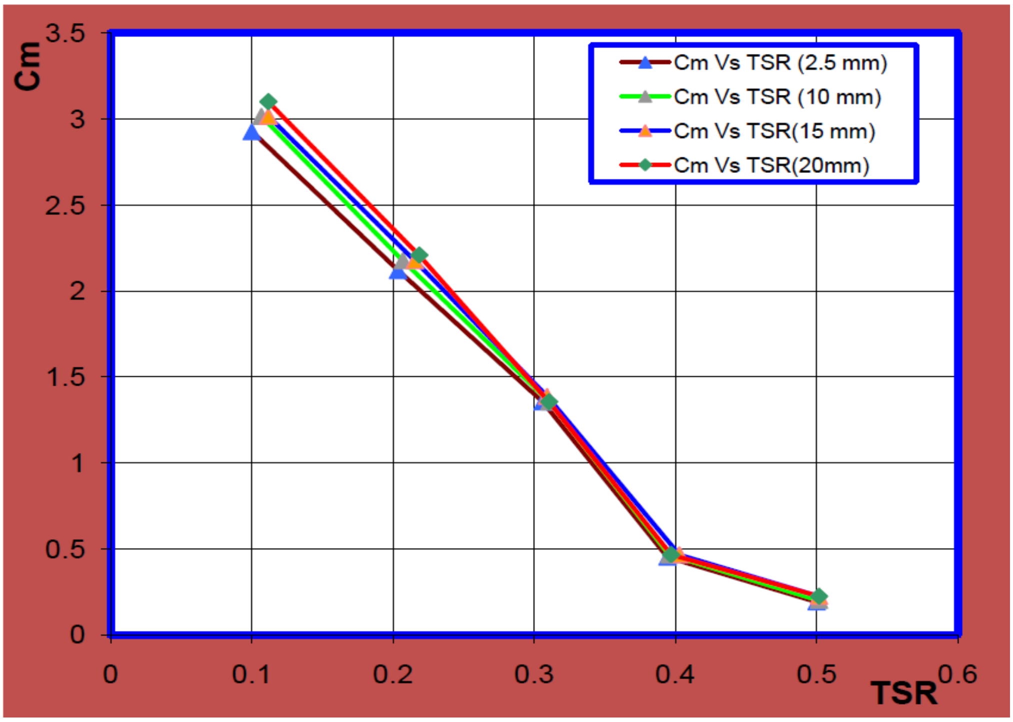

Fig. 21: The relationship of Cm against TSR for different blade thicknesses

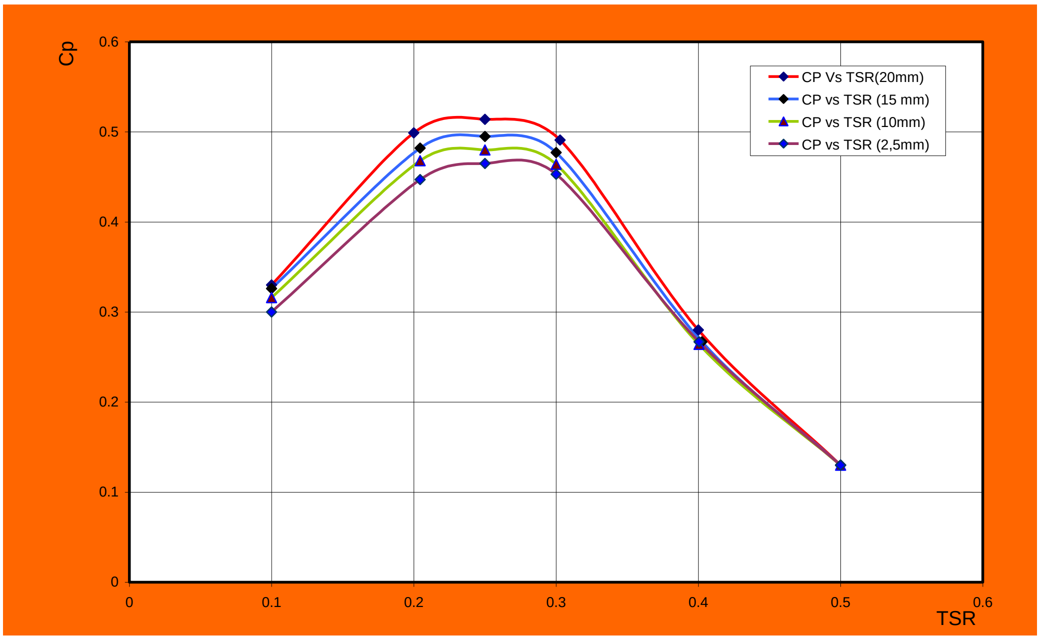

Fig. 22: The relationship of Cp against TSR for different blade thicknesses.

For the turbine which has 22 numbers of the blades, Cp becomes maximum when TSR equals to 0.2. On the other hand, Cp of the 18 blade number turbine becomes maximum when TSR equals to 0.3. In addition, figure 23 below shows the chart of Cp values against TSR for a turbine has 20 mm blade thickness.

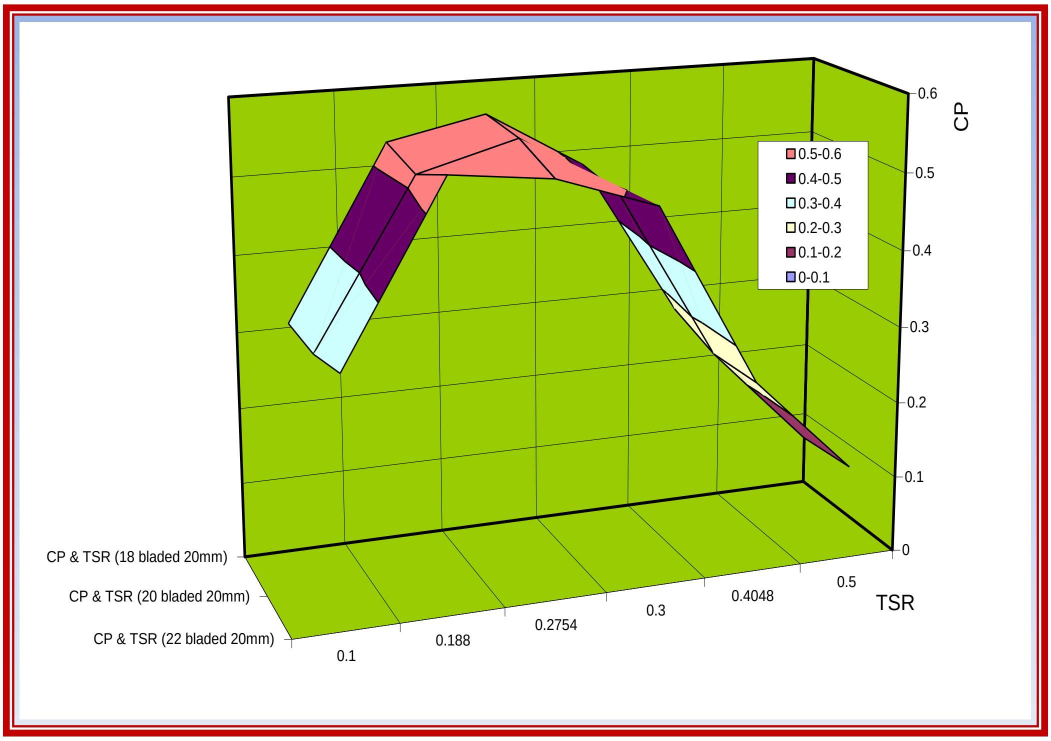

Fig. 23: Cp against TSR for different blade number.

Optimum performance for the turbine can be achieved with higher TSR and lower number of the blade. These properties help greatly in satisfying high rotation. Then, the air cannot pass easily between the blades. Furthermore, figure (24) below shows velocity vectors for TSR equals to 0.1.

The above figure demonstrates that the turbine, which has 22 blades, involves maximum blades for interacting with airflow to satisfy positive moments for extracting power. When TSR equals to 0.1 and 0.2, Cm and Cp are optimum for a wind turbine with 22 blades. However, this cannot satisfy when TSR equals to 0.4 or 0.5. The reason of that is the difficulty of air passing between the blades which reduce positive moments for extracting power. Therefore, the turbine, which has 22 blade numbers and smallest gap between blade, has minimum Cm and Cp. Additionally, figure (25) gives speed vectors when 0.5 TSR.

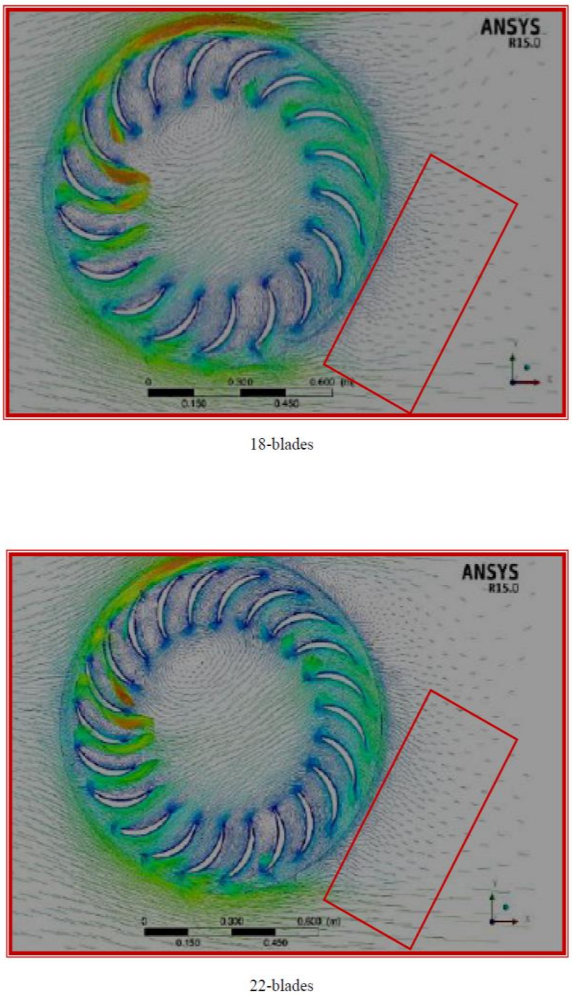

Fig. 25: The speed vector on turbine

(TSR 0.5)

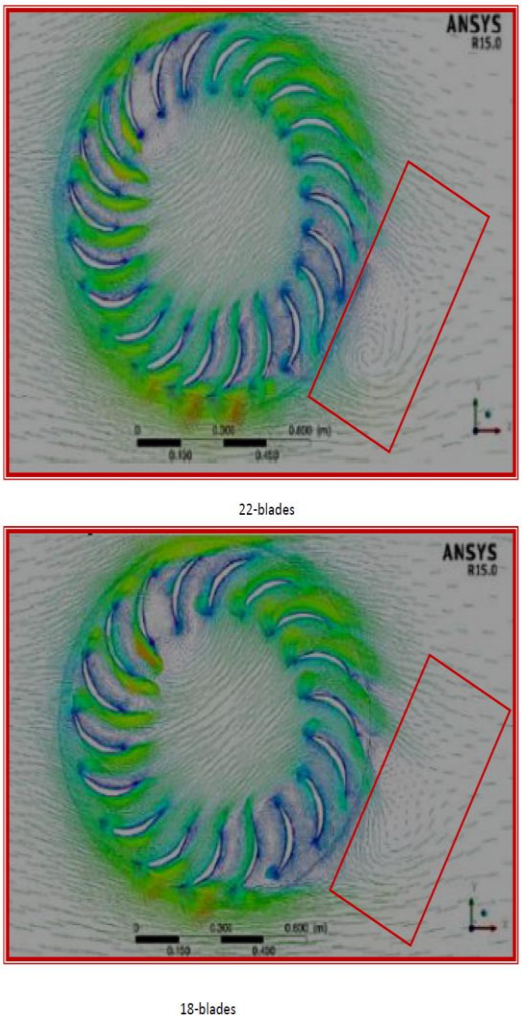

Fig. 24: The speed vector on turbine

(TSR 0.1)

6. Conclusions

The use of wind turbines for generating electrical energy is increased greatly in the 21th century. This is because power resource is renewable resource and does not have any pollution. The experimental results, which are obtained from two different groups, demonstrate the effects of designing parameters on the mechanical response of these turbines. This paper studies the performance of two types of turbines which have same aerodynamic profiles with various twist angles of blades.

The main conclusions are:

a) At best tip angle of the blades, highest power coefficients are similar if the aerodynamic blade profile is chosen correctly;

b) With increasing twist of the blades, tip angle has to be reduced which means the relationship of the blades between twists and tip angles are inverse

c) The mechanism of increasing twist angle must be applied on lower wind speeds with changing Cp about 10% overall working scale of wind speeds.

d) The value of Cp is very small for the rotor with 2 especially with rising of α; at upper α, which makes cut in speed of the turbine smaller.

e) The Cp of the turbine which has 6 blades is so lower as compared with Cp of the peers which involves 2 or 3 blades. This is because increasing blades number makes the varying area of cut in wind speed bigger without influence on the magnitude of power coefficient.

f) For all types of wind turbines which are tested in this research, the turbine, that has 20 mm blade thickness, has maximum torque coefficient as well as power coefficient. On the other side, the turbine with 22 blade number has best power coefficient. Lastly, the turbine, which involves 18 blade numbers, has the power coefficient better with respect to the highest TSR.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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خلاصة

تعتبر محركات الرياح واحدة من المصادر المهمة في توليد الطاقة الكهربائية. ذلك لان تعتبر من مصادر الطاقة المتجددة. كما انها في مقدمة المصادر الصديقة للبيئة.هذا البحث يتناول كيفية زيادة كفاءة هذه المحركات من خلال تسليط الضوء على العوامل الموثرة الرئيسية في في سلوك هذه المحركات. كما يتضمن البحث تقييم عن مدى اعتمادية معامل القدرة لهذه المحركات على معدل سرعة الرياح الخاص بامكان تنصيب هذه المحركات. يستخدم هذا البحث ايضا احد برامج المحاكات لدراسة سلوك المحركات مع تغيير عدد الريش وكذلك زوايها.

الكلمات الدالة: عدد الشفرات، زاوية الحافة، زاوية الالتواء، توربينات الرياح.