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Performance Analysis Of Vertical Axis Wind Turbine Blades Using Double Multiple Stream Tube Process

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Abstract

The interest in green energy in recent years is very noticeable, as this energy is a very important alternative that can replace fuel in many applications, most notably electric power generation, so work must be done to develop a form of this energy such as wind energy by working on the development of turbines. The DMST method provided by Qblade software is an integrated tool for making a simulation of a vertical axis wind turbine (VAWT). The simulation was carried out on vertical axis wind turbines, designing turbine blades according to symmetrical NACA0018, and calculating some parameters such as power, torque and power coefficient. It is found that this type of turbine can be improved by treating the blade edges that contribute to the turbine power loss, thus improving the turbine at low wind speeds.

Keywords: Wind Energy, Simulation, Qblade, DMST, VAWT, TSR.

تحليل أداء شفرات توربينات الرياح ذات المحور العمودي باستخدام عملية الأنبوب المزدوج المتعدد

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الخلاصة

إن الاهتمام بالطاقة الخضراء في السنوات الأخيرة ملحوظ للغاية، حيث تعد هذه الطاقة بديلاً مهمًا للغاية يمكن أن يحل محل الوقود في العديد من التطبيقات، وأبرزها توليد الطاقة الكهربائية، لذلك يجب العمل على تطوير شكل من أشكال هذه الطاقة مثل الرياح بواسطة العمل على تطوير التوربينات. وبالتالي، فإن طريقة DMST التي يوفرها برنامج Qblade هي أداة متكاملة لعمل محاكاة لتوربينات الرياح ذات المحور الرأسي (VAWT). تم إجراء المحاكاة على توربينات الرياح ذات المحور الرأسي، وتصميم شفرات التوربينات وفقًا لـ NACA0018 المتماثل، وحساب بعض المعاملات مثل القدرة، وعزم الدوران، ومعامل القدرة، ووجد أنه يمكن تحسين هذا النوع من التوربينات بمعالجة حواف الشفرات التي تساهم في فقدان طاقة التوربينات، وبالتالي تحسين التوربين عند سرعات الرياح المنخفضة.

1. Introduction

Interest in alternative energy in all its forms, whether wind, water, or solar energy, is absolutely necessary to replace the problems caused by fuel of all kinds in the environment

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and climate. Wind turbines are a good alternative and are a source of green energy. In addition to the world's need for electricity, the growing population has led to increase demand for energy consumption. It is necessary to resort to alternative energies among which is the power provided by wind turbines. As it is well known, the most prominent advantages of horizontal axis wind turbines (HAWT) and the vertical axis wind turbines (VAWT), that can be exploited in urban areas, is its acceptance of wind from any direction. A vertical-axis wind turbine simulation was made using Qblade and simulation steps were also made as a guide to the program [1]. The aerodynamic model is presented by applying it to the horizontal axis wind turbines and vertical axis wind turbine and simulating the blades of each of these turbines as dynamic parameters; the other parameters provided by Qblade has been calculated. How these parameters, including lift and drag, affect the performance of the turbines has been studied [2]. Using some transactions for a suitable wind turbine code (VAWT) design and focusing on the appropriate and optimal flap design for the best energy you can extract turbine [3]. Using the BEM approach, several transactions were mimicked, and turbine blades were designed and improved, with a code length of 1.2m with a capacity of less than 1Kw [4]. Through equations of momentum theories as well as elements of the blade to obtain equations to optimize the design of the blade, and through what Qblade allows to validate the calculated results, the turbine codes were designed by dividing the code into several elements [5-6]. The design was done using Qblade, as well as the simulation in the same program, as well as the Matlab Simscape Ocean Control Simulator; wind turbines were designed with focusing on increasing efficiency as well as making the blades less overweight using aluminium [7]. The vertical axis wind turbine type (Darrieus) blade was worked on by improving and correcting the default camber of Naca0021 and was found to have an effect on the improvement of the blade when simulated using Qblade [8]. With a two-dimensional simulation, the effect of the curvature in the rear edge of the Darrieus turbine blade was verified, by analysing the coefficients for blade fluctuations and at low wind speeds, this improvement in the edge of the blade was found to lead to an increase in the power factor [9-10]. Design variables affecting the performance of the turbine such as cord length, twist angle, and simulation work were studied through the element momentum method (BEM) offered by the Qblade program, where work was done to analyse and improve the blades of the turbine (less than 1kw), and to display some of the features provided by the program [11]. Using DMS, numerical models can be created so that they are simpler than CFD algorithms, to analyse and simulate vertical turbine-axis type (Darrieus) blades. This method is one of the most important numerical methods for calculating the aerodynamics of a fully wind turbine [12-13]. Since small turbines have low performance for several reasons, most notably rotor size, these turbine blades can be improved by working to improve more than one of these blades, such as the S 1210 and S 1223. After design, a simulation of the final design was done [14]. To analyse the efficiency of the VAWT turbine, design its own blade and simulate it, and to study some of the effect of some attack angle variables on the performance of the turbine at low wind speeds, the Qblade program was used [15-16]. The numerical simulation of the wind tunnel was conducted and the experimental analysis of the wind turbine from the rotor, the number of blades and the change in the length of the cord were studied. It was concluded that the increase of the power factor with the increase in the so-called rotor solidity as well as the increase in the number of blades. The simulation of this turbine was done using the Qblade program, where the work to improve the toughness of the rotor has a positive effect on the performance of the full and total energy [17]. To track the characteristics of the overall wind turbine (VAWT) structure, it is important that the design control, experimentally, reflects positively on the reality of wind turbines, so attention must be paid to studying aerodynamics significantly, particularly to the results, especially the measured torque and thus the wind

tunnel are fully simulated from the turbine design to the analysis and interpretation of aerodynamics [18].
This study aims to design the blades of a vertical axis wind turbine using (airfoil NACA0018).

2. Theoretical Equations

Power and power coefficient are among the most important factors when calculating the properties of a wind turbine. The power of a turbine depends mainly on both the ratio of mass flow and the wind velocity cube [19].

$$P = \frac{1}{2}\dot{m}\, u^2 = \frac{1}{2}\rho\, A\, u^3 \qquad (1)$$

Where: (P) is power of turbine in (Watt), (u) is velocity of wind in (m/s).
For the power and thrust coefficients, it can be calculated by the following equations [4]:

$$C_p = \frac{2P}{\rho\, A\, u^3} \qquad (2) \quad ,$$

$$C_T = \frac{2T}{\rho\, A\, u^2} \qquad (3)$$

Where:(Cp) is power coefficient, (C_T) is thrust coefficient.
The force affecting the object is called the parallel direction of the flow as the drag forces has a parameter called the drag coefficient, whereas the force affecting the object is called the natural direction of the flow direction as the lift forces and has its own parameter called the lift coefficient.

$$C_l = \frac{2l}{\rho\, A\, u^2} \qquad (4)$$

$$C_d = \frac{2d}{\rho\, A\, u^2} \qquad (5)$$

Where: (C_l) is the coefficient of lift, (C_d) is the coefficient of drag.

Tip speed ratio is the ratio between the angular velocity achieved by the turbine blades and the wind velocity intercepted by that turbine. It is an important factor, which is taken into account in the design of the turbine and especially in the design of the rotor, because it significantly affects the value of the turbine efficiency. The tip speed ratio is calculated according to the following equation [3].

$$\lambda = \frac{R\omega}{u} \qquad (6)$$

Where: (λ) is the tip speed ratio, (u) is the speed of wind in (m/s), (R) is the radius of rotor in (m), (ω) is the velocity of rotational in (rad s^{-1}).

3. Rotor Design and Simulation for VAWT

The design and simulation of a vertical axis wind turbine can be completed by three main steps, with the first step being the design of the turbine blade (Rotorblade design) and the next step is the design and simulation of the wind turbine through the so-called Rotor Double Multiple Stream Tube (DMST) simulator, and the third step is the design of the full system wind turbine, according to the schematic diagram in Figure 1.

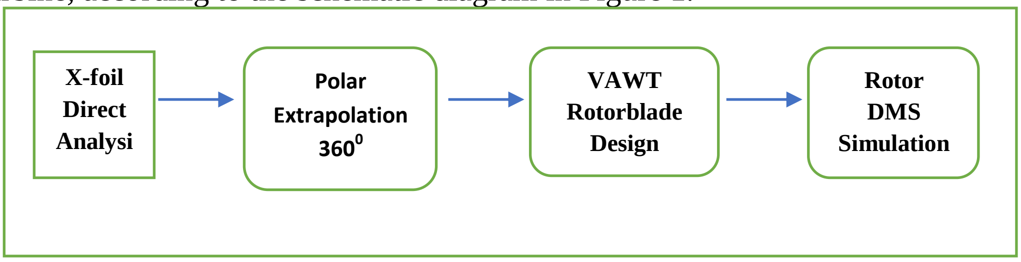


Figure 1-Schematic diagram for DMS simulation.

By using Qblade software (v0.963) and DMST [20], The vertical-axis wind turbine type (Darrieus) was designed and simulated. The first step of the design was to identify the important coefficients that determine the shape and dimensions of the blade in terms of height, radius and cord as well as other coefficients in addition to the similar airfoil NACA0018, which features a low starting torque. The shape of the blade was improved by making it straight. Table 1 shows the parameters of the rotor for 4 and 6 blades. Figure 2 illustrates the design of the blades of the vertical-axis wind turbine.

Table 1-Rotor design

names	***values***
Airfoil	Naca0018
Reynolds number	1000000
Blade height	2.5m
Rotor radius	1m
Chord	0.3m
Number of blades	4 and 6
Density of air	1.225 kg/m^3
Epsilon	0.001
Viscosity of air	0.000016547 kg/m-s
Relaxation factor	0.35
Roughness Length	0.01 m
Tip speed ratio	0.5-4.5
Area	5 m^2

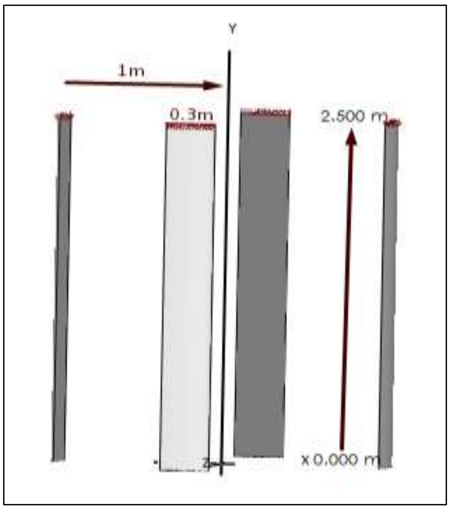
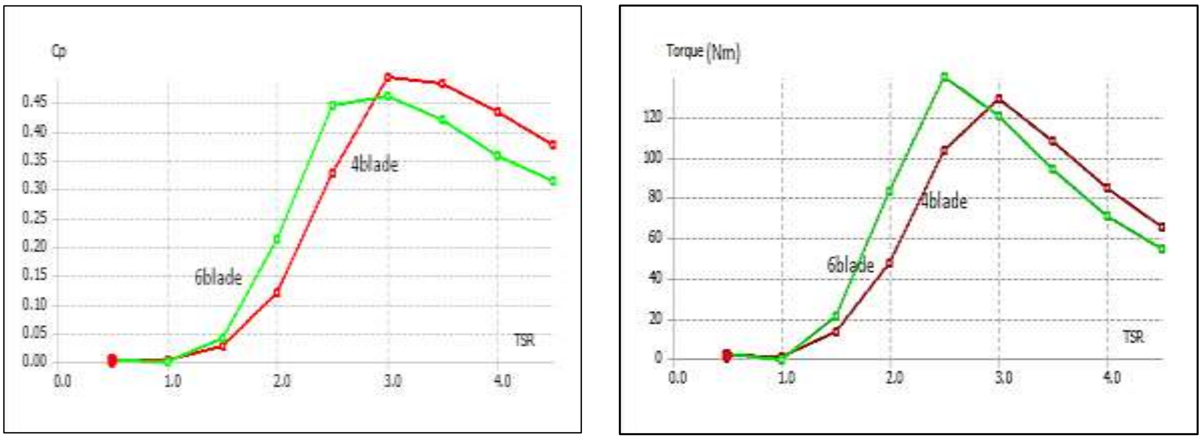


Figure 2-Vertical axis wind turbine model.

4. Results and discussion

4.1 DMST Simulation for VAWT

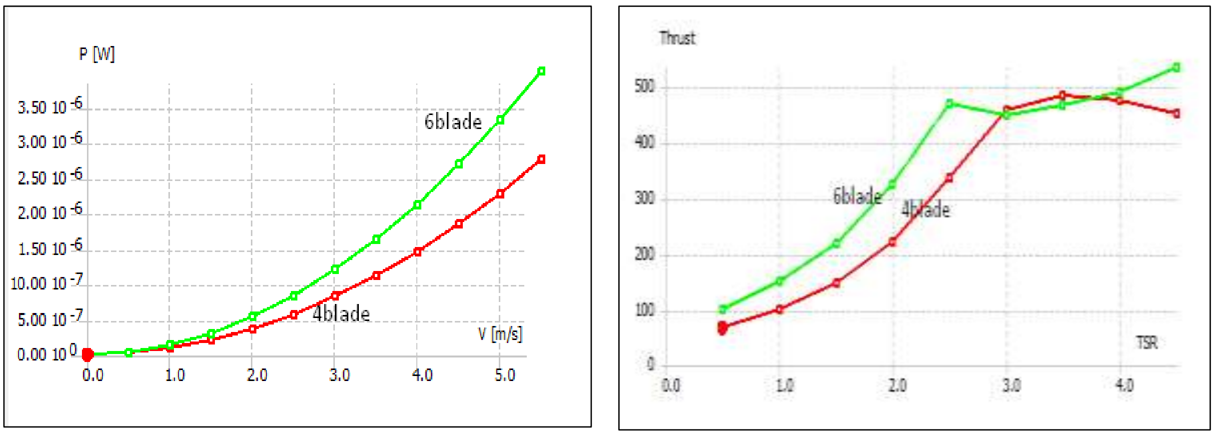
The DMAT feature allows us to do special simulation of the vertical-axis wind turbine, where the balance of momentum is combined with the forces of the blades, so the flowing air pass through the rotor against the wind once and with the direction of the wind once. Using a variable deflection approach, the best performance can be obtained depending on many coefficients such as the diameter, height, length and frequency of the rotor. Moreover, the DMAT character depends on the Angle Of Attack (AOA), which also depends on the speed of the rotating blades. A feature of DMST is that it gives results both accurately and quickly. Figure 3a shows a graph of the power coefficient (C_P) as a function of the tip speed ratio (TSR) of values (0.5- 4.5). When the number of blades was (4), the power coefficient increased with the increase of the tip speed ratio up to a value of 3 beyond which the power coefficient decreased. This shows that the best performance can be obtained for this turbine when the tip speed ratio is between (0.5-3). The power coefficient (Cp) had a maximum value of (0.59), which is known as the Betz limit [21]. This result is in agreement with that of Vergaerde et al. [18]. The same behaviour was noticed when the number of blades was 6, but with lower values of power coefficient. Torque changed with tip speed ratio, as shown in Figure 3b. It can be noted that that maximum torque was at TSR =2.5 for the 6 blades, while it appeared at TSR =3 for the 3 blades. Also, the maximum torque of the 6 blades was higher than that of the 4 blades.



(a) (b)

Figure 3-(a): Power coefficient versus tip speed ratio. (b) Torque versus tip speed ratio.

It is known that the increase in wind speed leads to the increase in power, which is verified in Figure 4a. It is also noted that power increases as the number of blades increases. Disturbance, a natural consequence at high speeds, can affect the thrust when the value of the tip speed ratio is between (3-4.5), as is noticed in Figure 4b.



(a) (b)

Figure 4- (a) The Power versus Velocity (m/s). (b) The Thrust versus Tip speed ratio.

Figure 5 shows the drag to lift forces (C_l/C_D) ratio versus azimuthal angle (theta) since both drag and lift forces are very important for the wind turbine. From this graph, it can be noted that at tip speed ratio of (1.5), the lift forces are of least contribution at the edges, whether upper or lower along the turbine. This leads to an important result, that the middle area of the blades does not contribute to loss of turbine power, and the focus must be on both ends of the blade for improvement.

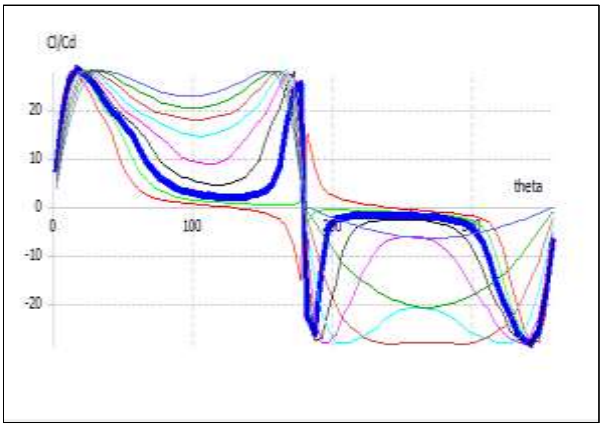


Figure 5- Cl/Cd versus Azimuthal angle theta.

It should be noted that the increase in the number of blades in the vertical-axis wind turbine increases the power factor (Cp). Table 2 shows the most important inputs of the simulation of this model of turbine.

Table 2- Some simulation input and calculation

names	***values***
Ground clearance	0.8
Blade 1 initial Azimuth (deg.)	270
Number of Timesteps	400
Simulation Length (s)	1.939
Rotor Rotation speed (RPM)	103.13
Pitch Range (deg.)	0-10

5. Conclusions

The DMST approach to Qblade, which has been developed, has a significant impact on the simulation of vertical-axis wind turbines (VAWT) because it takes many important transactions for a wind turbine. This approach can be relied upon and simulated before actual design. It can be concluded from this simulation that it is possible to improve the power of this type of turbine by addressing both ends of the blade and the upper and lower edges, since the medium area of this blade does not contribute to the loss of turbine energy, but rather is considered to be the largest contributor to the turbine power of the rest of the blade. The turbine can have the best performance at its highest power coefficient and torque. This occurred, for this turbine, when the tip speed ratio value was between (2.5 and 3). The height, radius of the blade, full turbine or the width of the tendon have a positive effect on the turbine power and in particular increase the power coefficient, which also increases with the increase the number of blades for vertical-axis wind turbines.

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