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Concept design of a Modified Airfoil Blade with Drag Assist for a Vertical Axis Micro-Wind Turbine

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Abstract

This paper presents the concept design of a modified airfoil blade for the vertical axis wind turbine in a micro wind power prototype which can be used for future research purposes. Airfoil blade turbine is one of the best turbine structures that possess the optimal speed characteristics. Although an airfoil turbine has many advantages, it still needs an efficient start-up mechanism. Hence changes were made in the airfoil blade design in order to enhance its start-up mechanism and some changes in the orientation of the turbine blades were done so that the structure has larger swept area. Tests were done on the proposed turbine structure and it is found that the new design is able to overcome the start up problem of the airfoil. A quantitative method is used to determine the efficiency of the proposed turbine, and the highest efficiency is found to be 49.22%.

Keywords: Micro-wind turbine, modified blade design, vertical axis, airfoil blade, drag assist, enhance start-up

Introduction

Due to the increase in the public awareness of the environmental issues such as pollution and climate change, the role of green energy becomes more and more important. One of the promising green energy is wind energy. During the last few decades, the technology of large wind turbine generators has seen considerable development. This technological development in combination with the increase in the cost of other sources of energy has made wind energy generation one of the world's fastest growing energy sectors in the field of alternative energy [1]. Some of the advantages of wind energy are (i) it is free, (ii) wind turbine produces no waste, (iii) wind farms are a novelty, (iv) wind turbines do not take much space, (v) supply power to rural areas, (vi) wind supply is plentiful, and (vii) wind is a great resource in less sunny areas.

It can be seen from the literature [2] that the worldwide installed wind energy capacity is more than doubling every third year. The market for new wind turbines shows a 42.1 % increase every year. Today, it is generally accepted and proved, that wind is far ahead of all other 'solar based' technologies, next to large–scale hydropower, regarding unit cost (kWh-price) and operational reliability[3].

The history of wind power shows a general evolution from the use of simple, light devices driven by aerodynamic drag forces; to heavy, material-intensive drag devices; to the increased use of light, material-efficient aerodynamic lift devices in the modern era. The evolution started with a windmill that was used to automate the tasks of grain-grinding and water-pumping and the earliest design is the vertical axis system developed in Persia about 500-900A.D.[4]. The first windmill in the world built for electrical production was in 1887 in Scotland built by Professor James Blyth. A year later in 1888 in the U. S. Charles Brush of Cleveland, Ohio built a large wind turbine used to generate electricity [5]. The Brush machine was a postmill with a multiple-bladed picket-fence rotor, featuring a large tail hinged to turn the rotor out of the wind. In 1891, the Dane Poul La Cour developed the first electrical output wind machine to incorporate the aerodynamic design principles (low-solidity, four-bladed rotors incorporating primitive airfoil shapes) used in the best European tower mills. The higher speed of the La Cour rotor made these mills quite practical for electricity generation [6]. The further development of wind generator electrical systems in the United States was inspired by the design of airplane propellers and (later) monoplane wings. In the next era, propeller type wind turbine was most commonly used. It was not stand alone turbine that generated electricity for grid, but installed in large amount for a certain area, called as wind farm. In 1980, U.S. wind power installed the world's first wind farm consisting of 20 wind turbines rated at 30 kilowatts each, on the shoulder of Crotched Mountain in southern New Hampshire; but it was a failure [7]. When airfoil blade turbines were introduced, most wind turbine blades where adaptations of airfoils developed for aircraft and were not optimized for wind turbine uses. In recent years developments of improved airfoil sections for wind turbines have been ongoing. Blades tend to have slightly higher lift airfoils closer to the root and lower lift airfoils near the tip. To gain efficiency, the blade is both tapered and twisted. The tapered, twisted and airfoil characteristics should all be combined in order to give the best possible energy capture for the rotor speed and site conditions [8]. In 2007 the super-powered MagLev wind turbine was first unveiled at the wind Power Asia exhibition in Beijing. Magnetic levitation is an extremely efficient system for wind energy. The full-permanent magnet system employs neodymium magnets and there is no energy loss through friction. This also helps reduce maintenance costs and increases the lifespan of the generator. It would also increase generation capacity by 20% over conventional wind turbines and decrease operational costs by 50% [9]. To date, wind forecasting models have been retrospective and have fallen short of accuracy. To help improve the predictability of wind supply, several organizations have made great strides in improving forecasting models. Catch the Wind has developed the Vindicator, a laser wind-sensor that is mounted on a wind turbine to determine wind-speed and direction, and orient the turbine into the wind. This enables turbines to see the wind in 3D before it reaches a turbine's blades and realign for optimal power output [10]. Bruce L. Jones [11] has proposed a unique spiral wind turbine which is capable of capturing the wind from every angle.

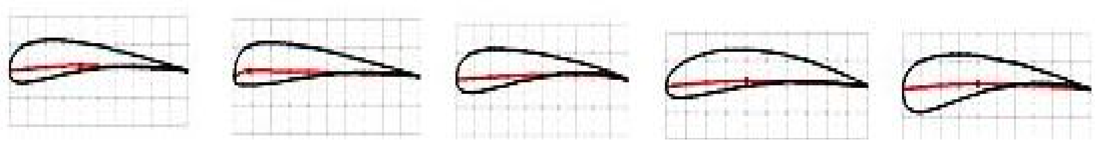
In 2007, researchers at Sandia National Laboratories developed a new wind turbine blade design (Named "STAR"-Sweep Twist Adaptive Rotor) in partnership with Knight & Carver of San Diego that promised to be more efficient than the available designs [12]. New airfoils have substantially increased the aerodynamic efficiency of wind turbines. Just like the wings of an airplane, wind turbine blades use the airfoil shape to create lift and maximize efficiency. According to Albert Betz, the theoretical limit of rotor efficiency is 59%. Most modern wind turbines are in the 35 – 45% range [13].

A good aerodynamics profile is essential to the blade design in order to keep the blade small and at the same time achieve higher efficiency. According to Stiesdal [14], the performance of the blade was heavily affected by the shape of aerodynamic profile. In [15], the authors have developed a small-scale vertical axis wind turbine for use in areas lacking adequate energy infra structure. The materials and methods of construction are selected to minimize cost as much as possible.In order to overcome the self-starting issues associated with VAWTs and low tip speed ratios, solutions such as high solidity, guide vanes, and drag tubes are considered.

Due to the increasing importance of wind power, an effective and efficient turbine design is essential to support the global energy demand. Although an airfoil turbine has better performance, it needs an efficient start up mechanism. To enhance the start up, a modified airfoil blade with drag assist is proposed in this paper for the vertical axis micro-wind turbine. This paper is arranged as follows: section 2 discusses the tests conducted on various types of vertical axis turbines, section 3 describes the proposed modified airfoil blade, section 4 presents the results obtained with the proposed turbine and section 5 depicts the conclusions and the final comments.

Airfoil Profile Selection

In order to choose a better vertical axis turbine structure, the performance of various turbines such as airfoil, savonius and spiral types are investigated and the results are presented in this section. Five versions of airfoil blades are generated using DesignFOIL_DEMO software and the best version is chosen for the proposed model. The five versions are labeled as airfoil1, airfoil2, airfoil3, airfoil4 and airfoil5 and are shown in Fig.1. The parameters of the airfoil profiles generated are given in Table 1. In order to determine the performance of the generated airfoil blades, a simulation is carried out on the 5 airfoil models for different angle of attack using VIRTUAL WIND TUNNEL and the lift coefficient, drag coefficient and pitching moment coefficient are generated. The two-dimensional lift coefficient is a relative measure of the lift potential that can be expected from a wing section tilted to a known angle-of-attack. The two- dimensional drag coefficient is a relative measure of drag potential that can be expected from a wing section tilted to a known angle of attack. The two-dimensional pitching moment coefficient is a relative measure of pitching moment or torque potential that can be expected from a wing section tilted to a known angle-of-attack. As the lift to drag ratio is the major concern in this simulation, compressibility effects and effects of adding insects to leading edge are neglected. The summary of the simulation result is shown in Table 2 and the graft of lift/drag vs. angle of attack is shown in Fig.2. From Fig.2 it is seen that airfoil4 has the highest lift/drag ratio of 125.2809 and hence is chosen for the proposed model. The picture of complete turbine is shown in Fig.3.



airfoil1 airfoil2 airfoil3 airfoil4 airfoil5

Fig. 1 Five versions of airfoil blades

Airfoil profile	airfoil1	airfoil2	airfoil3	airfoil4	airfoil5
Thickness Distribution					
Upper X	0.20	0.20	0.20	0.35	0.25
Upper Y	0.10	0.10	0.10	0.12	0.11
Lower X	0.10	0.10	0.10	0.10	0.10
Lower Y	-0.05	-0.05	-0.05	-0.05	-0.09
TE Height	0.002	0.002	0.002	0.002	0.002
Camber Line					
X/C Value	0.400	0.080	0.700	0.400	0.400
Y/C Value	0.020	0.020	0.020	0.020	0.020

Table 1 Parameters of the generated airfoil profiles

Two other kinds of vertical axis wind turbines namely savonius type and twisted savonius type (or spiral type) are built and shown in Fig. 4 and Fig. 5 respectively. The performance of the above three types of turbines are tested under three different wind speeds (wind speed1 < wind speed2 < wind speed3) and the results are tabulated in Table 3. From the results it is seen that the airfoil turbine has the highest speed compared to the savonius and spiral turbines.

Degrees	**L/D**				
	airfoil 1	**airfoil 2**	**airfoil 3**	**airfoil 4**	**airfoil 5**
0.0	73.9286	68.0233	85.5422	121.1111	83.3333
1.0	87.2941	80.1136	94.3182	120.8046	95.2809
2.0	99.0805	90.7692	103.0769	**125.2809**	101.3830
3.0	103.7634	99.7872	110.0000	123.4737	106.9072
4.0	109.5833	108.4211	107.8431	119.1262	106.0952
4.9	111.1881	-	-	-	**108.9815**
5.0	**111.9802**	111.3000	110.4717	113.8393	108.5321
5.2	-	-	**110.6542**	-	-
5.4	-	**113.2673**	-	-	-
6.0	109.2727	107.9091	110.1786	108.0328	105.5085
7.0	108.1197	108.1034	109.3220	101.2687	104.0000
8.0	107.3171	106.6667	106.3492	100.7971	102.8244
9.0	109.4400	108.9600	98.0142	92.2078	99.8561
10.0	99.8582	104.0000	95.1678	86.4671	92.4026

Table 2 Summary of simulation result

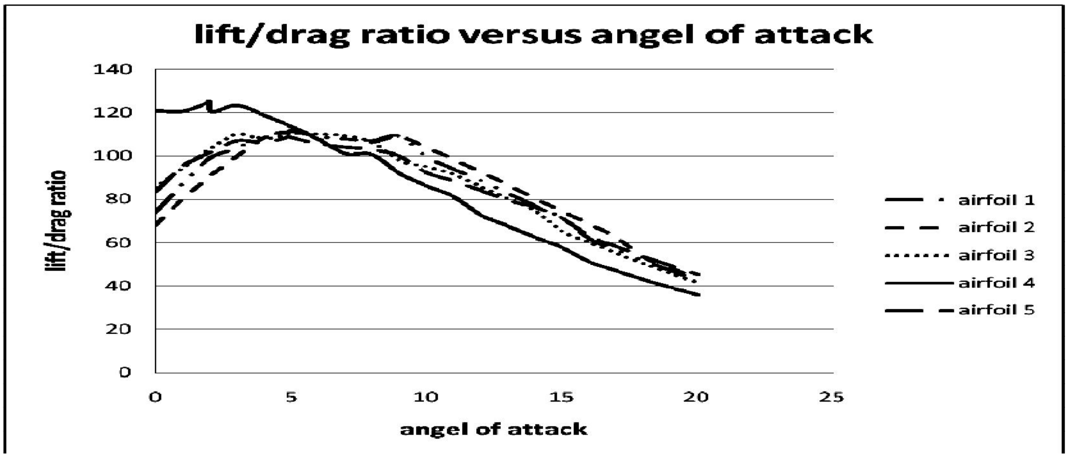


Fig.2 Graft of lift/drag ratio versus angle of attack

It was observed during the test that the airfoil type turbine was swinging forward and backward for a moment before it continuously rotated in the correct direction. This is because the force that moves the blades in the forward direction has to overcome a high static friction. This friction is reduced when the turbine starts to move and the force to move forward is significantly increased. This initial swing is reduced significantly at higher wind speeds. The savonius and spiral type turbines did not encounter this start-up problem.

Fig.3 Airfoil turbine

Fig.4 Savonius type

Fig.5 Spiral type

Type of turbine	**Wind Speed1**	**Wind Speed2**	**Wind speed3**
Airfoil	229.725rpm	295.575rpm	485.6rpm
Savonius Turbine	166.8rpm	176.6rpm	182.6rpm
Spiral Turbine	159.0rpm	175.6rpm	180.6rpm

Table 3 Turbine speed at various wind speeds

Therefore, it is concluded from the test that the airfoil turbine has the highest speed while the savonius & spiral turbines have a good start up characteristics. Hence, a new turbine model is proposed in the next section by combining the advantages of airfoil turbine and drag force based turbine.

Proposed Turbine

In this section, a new turbine model is proposed so that the start up problem of airfoil turbine is overcome. To overcome this, the airfoil4 blade is modified by adding a drag force structure. One end of the blade is designed in such a way that it gives resistance to the wind & hence helps in the start up process while the other end is airfoil base structure which helps to achieve higher speed. The blade is shown in Fig.6. Note that the blade is designed in such a way that the upper surface of the blade has larger area than the lower surface at the airfoil end [Fig. 7 and Fig.8]. This unequal area is for the purpose of letting out the wind that is captured inside the blade and to reduce the turbulence.

Fig.6 Improved blade

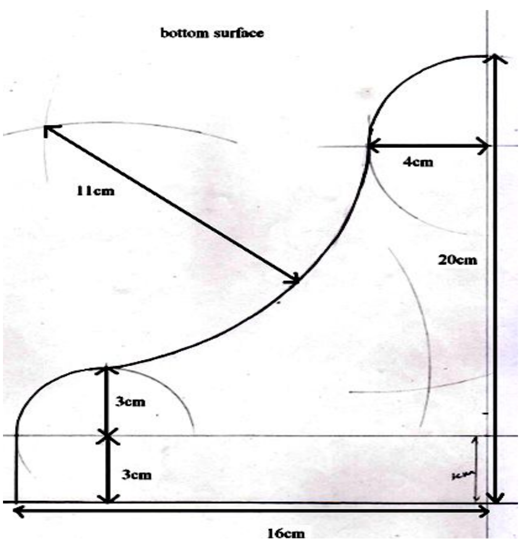


Fig.7 Bottom surface of the blade

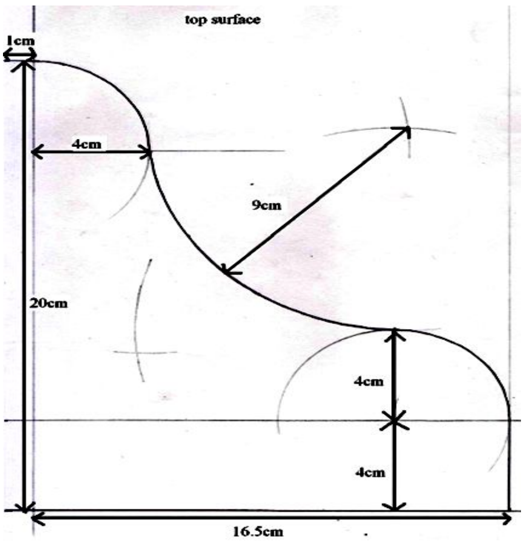


Fig. 8 Top surface of the blade

Besides that, in order to capture the wind from a wide range of angle and achieve higher efficiency, the turbine blades are oriented horizontally and distributed uniformly at the main shaft. The top view and the side view of the proposed turbine are shown in Fig.9 and Fig. 10 respectively. In this proposed model, it is assumed that the drag force structure that is incorporated into the airfoil blade will not affect the speed of airfoil. The results of the test conducted on the proposed turbine are given in section 4.

Fig. 9 Top view of the new turbine

Fig. 9 Side view of the new turbine

Results and Discussion

The value of the turbine upstream and downstream wind speeds together with the value of corresponding power coefficient C_p are given in Table 4. The turbine efficiency C_p is calculated using the following equation:

$$C_p = \frac{\left[1+\frac{V_0}{V}\right]\left[1-\left(\frac{V_0}{V}\right)^2\right]}{2} \tag{1}$$

where, V is the upstream wind speed (ms^{-1}) and V_o is the downstream wind speed (ms^{-1}). The efficiency of the new turbine is determined at various wind speeds (ranging between 4.6 m/s and 8.5 m/s) and the results are tabulated in Table 4. During the turbine test, it is observed that the start-up problem has been eliminated. Fig. 10 shows the graph of turbine efficiency versus upstream wind speed. From the graph, it is found that the highest efficiency of 49.22% occurs when upstream wind is 7.2 ms^{-1}.

V (m/s)	4.6	4.8	5.1	5.4	5.7	6.2	6.7	7.2	7.6	8.1	8.4	8.5
Vo (m/s)	4.38	4.49	4.59	4.6	4.64	4.6	4.47	4.53	5.08	6.27	7.15	7.49
Cp	0.0901	0.1179	0.1779	0.2453	0.3043	0.3922	0.4622	0.4922	0.4612	0.3554	0.2547	0.2097

Table 4 Turbine efficiency

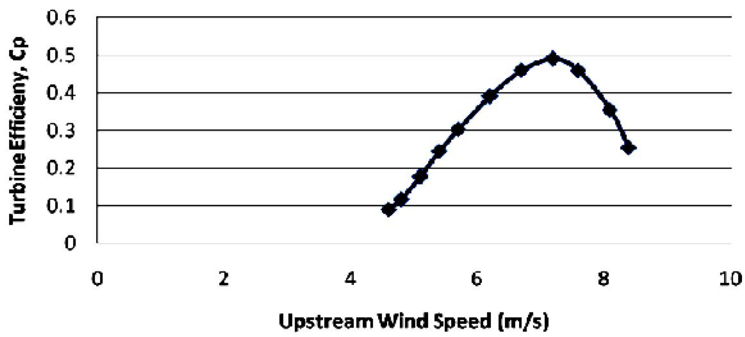


Fig.10 Turbine efficiency

Conclusion

In this paper, the advantages of airfoil turbine & drag force based turbine are combined and a new airfoil blade with drag assists is proposed for the vertical axis wind turbine which can be used for future research purposes. Furthermore, in order to capture the wind over a wide range of angle and achieve higher efficiency, the turbine blades are oriented horizontally and distributed uniformly at the main shaft.

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