OPTIMIZED DESIGN AND IMPLEMENTATION OF VAWT FOR BATTERY CHARGING APPLICATIONS

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Abstract : This paper presents an optimized design and implementation of vertical axis wind turbine (VAWT) for battery charging applications. VAWT is becoming more popular than a horizontal axis wind turbine (HAWT) which is used conventionally. Most of the VAWTs are installed in high wind speed areas. An optimized design proposed in this paper aims to make VAWT to be efficient and operative even at low wind speeds.This turbine is specially designed to serve the purpose in low wind speed areas where wind speed is not crossing beyond 5m/s. Based on the output voltage of the turbine, converter can be designed to boost the output voltage and charge a battery of 12V. The main objective of operation of VAWT is charging of a battery.The turbine output has to be converted into DC since the output obtained from a wind turbine is AC. Turbine blade profiles are aerodynamically shaped with NACA0018 series. Modifications are carried over NACA0018 blade profile and an optimized design is obtained. Basic vector analysis and laws of motion are applied to test the performance of a new design theoretically. For simplicity in designing NACA0018 symmetrical profile is used and a model is fabricated as per the design parameters and tested practically.

IndexTerms **-** VAWT, Resultant Vector, Blade profile, NACA airfoil series, Darrieus Wind Turbine, Savonius Wind Turbine.

I. INTRODUCTION

VAWTs are generally classified based on the purpose to be served.Savonius and Darrieus wind turbines are popularly used VAWT. Selecting among these turbines dependon whether the turbine is to be installed in high wind speed regions or low wind speed regions. The objective here is to make the turbine run at greater rpm even with low wind speeds. The turbine is expected to have low torque and with self-starting feature.

Darrieus H-type rotor is considered for the analysis. This lacks with self-starting feature which is incorporated in the modified design.

The turbine is made to utilize maximum area of its blades to capture the kinetic energy from the wind. In order to achieve this, time taken by the wind to hit the turbine blade surface is reduced. This helps in increasing the resultant force that enhances the angular speed of the turbine.

The basic principle of operation is intended to achieve very low cut in speed [1]. Effect of aspect ratio and significance of Reynold's number is explained in [2]. Guide vanes are introduced in [3] and its application in low wind speed regions is analyzed.

Understanding the importance of aerodynamics is needed for fabrication of the turbine. Positioning of the blade for optimum operation along with various other parameters and suitability among classification of VAWT adds up in obtaining the expected design. Evaluation of wind intensity and topography of the land helps is approximating certain parameters [4-8].

Number of blades of a turbine play very important role in the design process [9]. Next step is to know performance of the turbine and factors affecting its operation [10-11]. Tip Speed Ratio is one of the performance parameters of VAWT that is related to efficiency of the turbine and hence to the power coefficient [12]. Wind velocityis assumed to be a vector and resultant is estimated by referring [13].

In the proposed design, with compact size of the turbine it is proved that it produces nearly same output compared to turbines having almost double the cross sectional area and also wobbling will be reduced which is normally found in VAWT.

A stable output can be obtained that can be used for battery charging applications by employing a suitable converter used for renewable applications.

Relation between force and time is derived and magnitude of the resultant force is compared when wind velocity vector is acted upon existing profile of NACA0018.

II. BLADE PROFILE OF THE WIND TURBINE

2.1 Effect of AoA on Geometry of the Blade Profile

Case 1: Illustration of Modified NACA0018 profile

Angle formed between the chord line and the velocity vector is termed as Angle of Attack (AoA). This section explains how AoA is measured for the modified NACA0018 profile. To incorporate self-starting feature the shape is modified to pick up speed at a low wind velocity. Wind stream is assumed to flow from an infinite distance. One of the vectors of wind stream hits a point on the blade surface. This is shown in Fig.1.

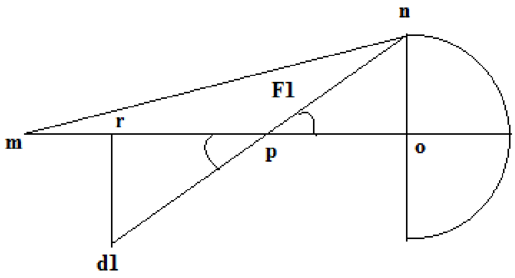

Fig 1: Illustration of Modified NACA0018 As A Turbine Blade Profile

mo = Chord line where as 'o' is the chord center.

d_1 is some arbitrary point from where wind velocity vector F1 originates and hits at point 'n'.rd_1 is also drawn perpendicular to mo.Δrpd_1 and Δpon form a right angled triangle.

$$\llcorner rpd_1 = \llcorner npo \text{ (Vertically opposite angles)} \quad (1)$$

These angles form AoA as the angle is measured at the point of intersection with a chord line.

$$\text{Let } \llcorner npo = \alpha_1 \quad (2)$$

'no' is the side opposite to AoA(α_1)

Case 2:Illustration of Proposed Turbine Blade Profile

By keeping the chord length (mo) same illustration is continued.

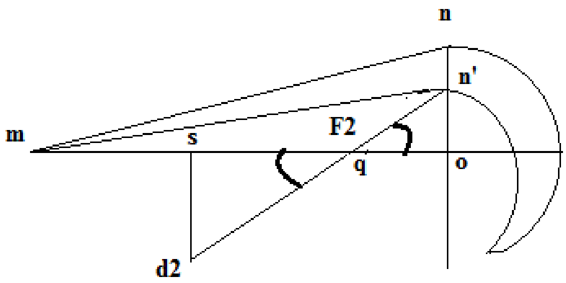

Fig 2: Illustration of Proposed Turbine Blade Profile

'no' and 'sd_2' are drawn perpendicular to mo and n' is the point lying on it.Point d_2 is selected so that the velocity vector F2 hits the surface of the turbine at point n' and intersects line mo at point q. And also

$$md_2 = md_1 \quad (3)$$

Δsqd_2 and $\Delta qon'$ are both right angled triangle.
α_2 is an AoA for the proposed design.

Comparing Fig 1 and 2 and referring the triangle law, it is clear that

$$on > on' \quad (4)$$

The proposed design is an enclosed structure. 'n' is a point on the outer surface of the blade and 'n'' is the point on the inner surface. Hence, relation (4) is quite obvious as per the geometrical assumptions made.

Therefore

$$\alpha_1 > \alpha_2 \quad (5)$$

From the relation obtained as in (5) it is clear that the new design proposed reduces the AoA. This reduction is expected to reduce the turbine vibrations while running.
Hence, it is proved that the proposed design can perform better than the turbine blade with modified NACA0018 profile.

2.2 AoA and Resultant Vector

Vector representation of Fig. 1 and 2 is shown in Fig. 3 (a) and (b). V_n is the vertical component that has to be reduced and V_t is the horizontal component that enhances the turbine angular speed and must be increased.

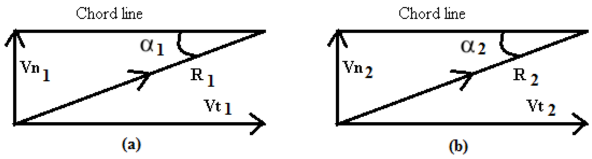

Fig 3: AoA and Resultant vector

From the above Fig.

$$\tan\alpha_1 = V_{n1}/V_{t1} \quad (6a)$$
$$\tan\alpha_2 = V_{n2}/V_{t2} \quad (6b)$$

In general,

$$\alpha = \tan^{-1} Vn/Vt \quad (7)$$

This proves that increasing horizontal component decreases the value of α and increases the turbine angular speed.

2.3 Analysis of Force on The Proposed Design

Wind has no definite direction of flow. Proposed blade profile must capture the effective wind intensity and increase the magnitude of resultant force. In this section relationship between force and time is illustrated and shown how the turbine blade gets accelerated according to Newton's laws of motion.

Assumptions made:
1. Force is a factor of time.
2. Intensity of force reduces as the distance increases and hence time.
3. Wind velocity vectors are assumed to flow from a source placed at ∞ and every velocity vector is considered parallel to one another.
4. Speed of every individual velocity vector is assumed to be same.
5. Normal environmental conditions are considered. Severe circumstances are not taken into consideration for preliminary illustrations.
6. Forces acting below the chord line tend to reduce the angular speed of the turbine. Only forces acting above the chord line are considered for illustration.

Case 1: Illustration of Force on Modified NACA0018 blade profile

Forces F_1, F_2 and F_3 are acting on the blade as shown in Fig. 4. F0 is acting along the chord line at 0^0 of AoA. F_0 is acting horizontally. No force has same magnitude when it hits the surface of the turbine blade. Therefore all the forces are unequal in magnitude.

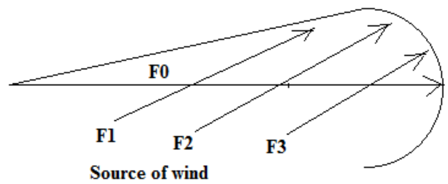

Fig 4: Illustration of Force on Modified NACA0018 blade profile

F_1 takes time t_1 to reach the turbine surface, F_2 takes time t_2 and F_3 takes time t_3 seconds. Similarly, there are 'n' numbers of forces acting on the turbine blade F_n being the force taking time t_n seconds to hit the turbine surface. Distance travelled in the specified time by these vectors is also different. F_0 takes time t_0 seconds to hit the surface. Due to variations in the magnitude of forces and time, average values are determined.

Let

T_1 = Average time taken to accelerate the turbine with modified NACA0018 profile.

$$T1 = \frac{t1+t2+t3\ldots\ldots\ldots+tn}{n} \quad (8)$$

Case 2: Illustration of Force on the Proposed Design

F_0 being the same, F_1', F_2; and F_3' are acting on the blade and takes time t_1', t_2' and t_3' respectively to hit the turbine blade.Average time is determined in a similar way. Due to the new design, there will be change in the time quantity and hence resultant of force.

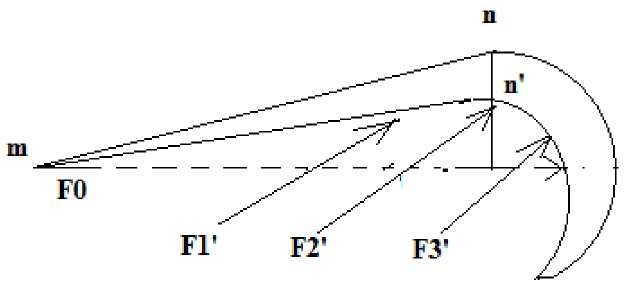

Fig 5: Effect of Force on the Proposed Design

Let

T_2 = Average time taken to accelerate the turbine for a proposed design.

$$T_2 = \frac{t1' + t2' + t3' ......+ tn'}{n} \quad (9)$$

Forces take less time to hit the turbine surface in the proposed design. Fig 2 and relation (7) well explains that horizontal component increases and hence the resultant velocity vector. From Fig 5, we notice that F2' hits at point n'. Point n' is close to chord line and point 'n' is farther. Intensity of force is more at point n'. Point of action is near from the wind source in case 2 compared to case 1.

$$\text{Therefore, } T_1 > T_2 \quad (10)$$

2.4 Force and Time

A relationship must be developed between force and time that helps in proving intensity of force is greater in the proposed design. Laws of motion can be applied to understand the same. According to Newton's second law, Force acting on any object is directly proportional to the acceleration of the object. Mass of an object is treated as constant.

Therefore, Force = Mass X Acceleration

$$F = m.a \quad (11)$$

'F' is measured in Newtons, 'm' is measured in kgs and 'a' is measured in m/s^2.'a' is an acceleration of an object due to change in the speed with respect to time. If 'u' is the initial velocity, 'v' is the final velocity of an object and change in the velocity is taking place in time't' secs. Object in this case is VAWT that gets accelerated due to variation in the wind speed.

Turbine starts from its state of rest and speeds up to v m/s. Therefore,

$$\text{Final velocity } v = \text{distance} / t \quad (12)$$

Mass 'm' of the turbine is constant. If only time component is considered,

$$F \ \alpha \ 1/t^2 \quad (13)$$

From equation (13) it is clear that 'F' changes inversely as square of the time. Even a small change in time causes a considerable change in the resultant force.

From the definition of Newton's laws itself it is clear that higher the force, greater is the acceleration of the turbine.

III. DIMENSIONS OF THE TURBINE

3.1 Length of the chord

Path covered by the turbine is a circle. A circle is divided into 6 equal parts. Every alternate part will decide the length of the chord.

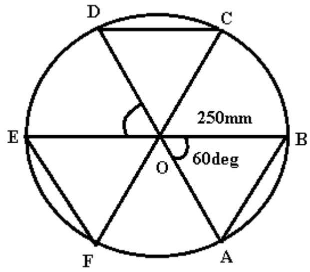

Fig 6: Initial Determination of Blade Dimensions

Each section is of 60^0 and the triangle drawn is an equilateral triangle. Hence the chord length will be equal to the radius of the turbine.

AB= length of the chord

For NACA0018:

0: first and second digits indicating symmetry of an airfoil

18: Last two digits with 18% of chord length and thickness of an airfoil.

If Diameter of the turbine is 500mm

18% of chord length = (0.18) (250) = 45mm

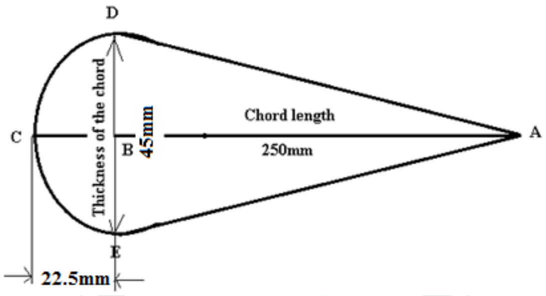

Fig.7 Airfoil Dimensions

The leading edge of an airfoil is a circle and thickness is its diameter. Therefore from the fig.7, DE = diameter which is thickness itself. This is calculated as 45mm. BE is the radius of the circle formed. Hence,

$$\therefore BE = BD = BC = 22.5mm$$

3.2 Proposed Geometry of the Turbine Blade

Keeping the basic geometry of NACA0018 the following modification is carried out.

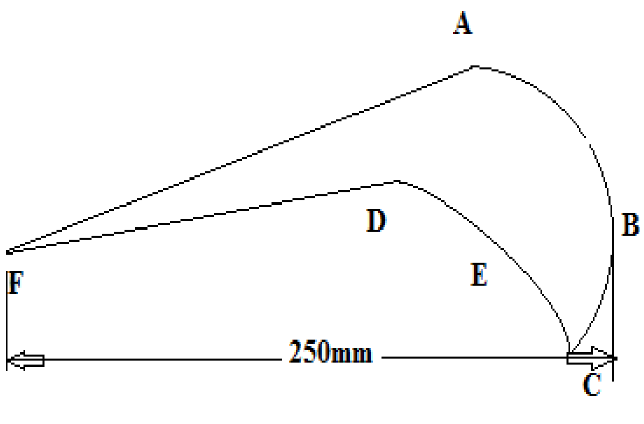

Fig 8: Proposed geometry of the turbine blade

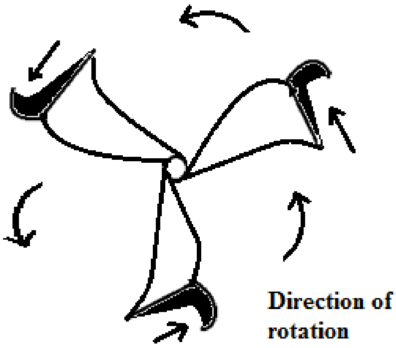

Fig 9: Top View of the Proposed Turbine Assembly

Turbine blades are connected and supported by an aerodynamic shape that enhances the speed of the turbine.The blade is supported at its leading edge and also at the trailing edge. The curved support at the leading edge pulls it faster and the support provided at the trailing edge protects the blade from vibrations during higher rotational speed.

3.3. Determination of Aspect Ratio

Aspect ratio is defined as the ratio of diameter of the turbine to height of the turbine. This ratio should be always greater than 1 and less than 2 for optimum operation. Therefore aspect ratio is selected between these two limits as 1.5.

$$\text{Aspect ratio} = \text{Radius R/ Height H} \quad (14)$$

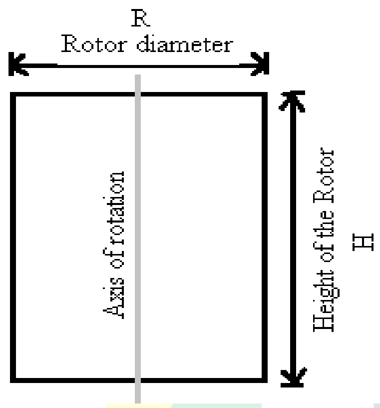

Fig 10: Area Swept By VAWT

Diameter of the turbine = 500mm; Aspect ratio = 1.5;
Height of the turbine = 333.33mm which is approximated to 350mm.
Area of the turbine = 0.5 X 0.35 = 0.175 m^2

3.4 Final Dimensions of the Blade

Dimensions are finalized by considering the aspect ratio and minimum possible area which is sufficient to generate electricity suitable for battery charging purpose. The above mentioned dimensions are shown pictorially.

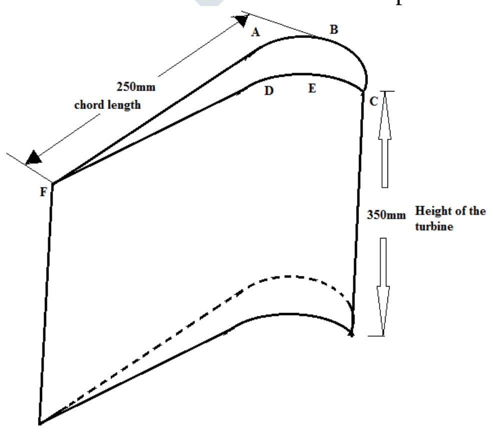

Fig 10: Final Blade Profile

IV. DETAILS OF THE FABRICATED MODEL

Fig 12: Fabricated Model

Fig 13: Top View of the Turbine

Fig 14: Stator on Which Turbine is Placed

Material used: M S Steel

Suggested Material for blades: Fibre (especially for Low wind speed regions)

V. RECORD OF OBSERVATIONS

Table .1 Observation Table

Sl.No	Voltage	Current	Wind Speed
1.	3V	4mA	3m/s
2.	3.25V	4mA	4m/s
3.	4V	5mA	5m/s
4.	4V	5mA	5m/s
5.	5V	5mA	6m/s

While testing the setup it is observed that the bearings used are subjected to more weight. Suitable bearings are to be used for free rotation of the turbine.

VI. CONCLUSION

The compact size of the turbine with optimized design has resulted in producing a better output that can be boosted up to the required level. The output current is not sufficiently high. Increasing the area of the turbine will result in getting higher output current and higher turbine output power.

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