Optimization of Small Wind Turbine at Low Speed

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Abstract— Wind energy is an easily available renewable energy source. A turbine is a device that can convert wind energy into useful electrical energy. Wind energy is zero cost, affordable, reliable, and almost maintenance-free. That small wind turbine is applicable anywhere However, when sized properly and used in optimal working conditions, small-scale wind turbines could be a reliable energy source and produce low-cost valuable energy not only in rich countries but also in non-developing applications in locations that are far away from the main power in countries. Small-scale wind turbines are becoming a more area promising way to supply electricity in developing countries. The small-scale wind turbine blade has quite different aerodynamic behavior than their large-scale wind turbine. A small turbine can be installed for less energy requirement. Small wind turbines operating at low wind speeds regularly face the problem of less performance due to the profile of blades, angle of attack, twist angle, more drag of the blades. To overcome these problems we select an airfoil shape blade which is NACA 4412 which has a good result at a low speed. We are trying to modify it profile and design made using Creo software and taking some result by using Q-blade software.

Keywords: NACA4412, Q-Blade, Small wind turbine-blade, angle of attack

I. Introduction

We have all seen the occasional massive wind turbine in rural farms or in some parts of the ocean show form which is exactly what the wind turbines are contributing to the future of sustainable energy for the expansion of the global population. Is it important to know what wind is? The pressure velocity causes the air to flow with the corresponding kinetic energy. The purpose of the wind turbine is to convert that energy into useful work that is done by expert and guided blade design. Each blade with an airfoil provides a lifting force that drives the airfoil to rotate in a circular motion. Which of these electric generators runs? Are the aerodynamics of wind turbines complex? This is because the total energy cannot be converted into useful function by which the available energy is obtained. This is a measure of the energy efficiency of wind turbines. We always have a wind turbine with a maximum useful energy coefficient of only 59.3%. Which is termed to be as best limit which is also called to be betz law at any point of time if you do not know about what exactly mean by betz limit.

II. Design Concept and Theory

A. Theoretical Maximum Efficiency

High turbine efficiency is desirable for the growth of renewable energy and should be maximized within the appropriate production limits. The energy (p) carried by the moving wind is expressed as the sum of its kinetic energy [Equation (1)]:

$$\frac{1}{2}\rho\, Cp\, AV^{3} \tag{1}$$

ρ = Air Density
A = Swept area
V = Air Velocity

There is a physical limit to the amount of energy that can be removed, independent of the design. The kinetic energy loss and the subsequent velocity of the energy are maintained in a flow process. The act of reducing the wind speed on a turbine is the magnitude of the energy used. 100% wind energy extraction is not possible. Not all wind kinetic energy can be used as zero flow conditions cannot be achieved. This principle indicates that the wind turbine efficiency does not exceed 59.3%. This parameter is commonly referred to as the power coefficient CP, where the maximum CP = 0.593 bets limit [6]. Betz's theory assumes a constant streamline velocity. Therefore, any rotating force such as turbulence (tip damage) caused by wake rotation, drag, or vortex shedding will reduce the maximum efficiency. The performance loss is usually minimized by Increases wake rotation Avoid low tip speed ratio, Choose airfoils with high lift for drag ratio Featured Tip Geometry, In-depth explanations, and the analysis can be found in the literature [4, 6]

B. HAWT blade design

We are focused on using maximum wind energy to transfer to useful work. We are trying to set up one that changes its profile and areas as the wind speed changes. We are going to change the blade design according to our requirements like a flexible wind blade that is working at high speed. Blades are very sensitive to changes in profile to design HAWT. In this section, we briefly discuss the other key parameters that affect the performance of HAWT blades.

C. Tip Speed Ratio

The tip speed ratio, defined as the relationship between rotor blade speed and relative wind speed [Equation (2)], is the most important design parameter around which all other optimal rotor parameters are calculated:

$$\lambda = \frac{v}{V} = \frac{\omega r}{V} = \frac{2\pi f r}{V} \tag{2}$$

λ Tip speed ratio(TSR)
ω Angular velocity (rad/s)
v Rotor tip speed (m/s)
r rotor radius (m)
V Wind speed (m/s)
f Rotational frequency (Hz)

D. Tip Speed Ratio

Factors such as efficiency, torque, mechanical stress, aerodynamics, and sound should be considered when choosing the right tip speed. Turbine efficiency can be increased at higher tip speeds [4], although this increase is not significant when considering certain penalties such as increased noise, aerodynamic and centrifugal stress.[6]

The most important element in wind turbine design is TSR.TSR is a dimensionless component defined as TSR which is usually denoted by λ The rotor tip divided by the incoming wind speed is equal to the TSR and there are no units, they are dimensional components so what exactly is now and can also be represented λ is the rotor tip speed ratio depends on the blade airfoil profile. The rotor tip speed ratio depends on the number of blades and the most important of the two types of wind turbines on which the rotor tip speed ratio generally depends, with which the three blades wind turbine operates. The tip speed ratio between six and eight is usually the highest reported value which is higher than a TSR is always preferable and desirable as it allows for high shaft rotational speeds and results in the most efficient operation of the power generator. But apart from having a high TSR, we have a lot of disadvantages of having a high TSR. The blade tips are rotating at a speed of 1 meter per second or experience a reduction in the leading edge of the blade. Noise due to high rotor speed. Vibration is another big problem. Due to the high TSR, some drag or tip losses have reduced the rotor efficiency. This is all a big shortcoming.

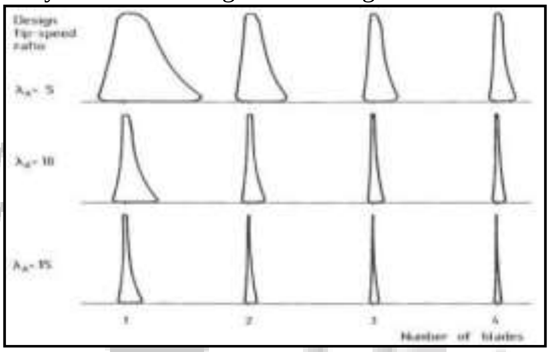

Fig. 1: Optimal blade plan shape foralternate design tip speed ratios andnumber of blades [5].

The demand for higher tip speeds reduces the width of the lower chord resulting in narrower blade profiles. This reduces the use of materials and can reduce production costs. An increase in centrifugal and aerodynamic forces, however, is associated with higher tip velocities. The increased strength indicates that difficulties exist in maintaining structural integrity and preventing blade failure. As the speed of the tip increases, the aerodynamics of the blade design becomes more critical. Blades designed for high relative wind speeds develop low torque at low speeds. This results in rapidly higher reductions [10] and difficulty in auto-starting. Increasing the volume is also related to increasing the tip velocity as the sound increases approximately to the sixth power [4, 11]. Modern HAWT typically uses a tip speed ratio of nine to ten for two-bladed rotors and six to nine for three blades. [5,6].

E. Aerodynamic Forces

Aerodynamic forces drive the rotor around and you will be able to calculate the lift in the blade section on the basis of air The role of the wind turbine is to remove the wind and the speed from the normal power and we know that then this kind of work to break the wind because the wind speed but there is more current in the stream and I Would like to said how the wind turbine looks like on a real turbine the wind is coming towards us from the front and we imagine that we wash some of the fluid that travels to the outer form and then rotates it through the plant which means that this fluid kind of meets the rotor and rotates it Forced because the wind around the rotor is also forced to force the fluid. Rotating the rotor in the opposite direction to that fluid parcel will gain speed so that this type of mesa rotates the rotor and gains speed in the fastest direction. We are able to describe the current flowing in the area around the blade in terms of the velocity triangle.

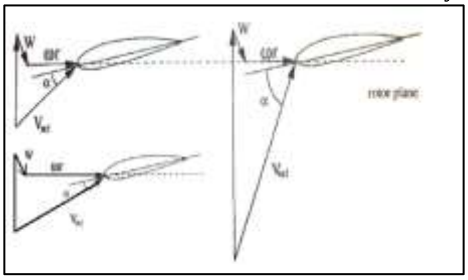

Fig. 2: Pitch and Twist with Velocity Triangles [22]

III. NACA 4412

National Advisory Committee for Aeronautics (NACA) four and five-digit designs have been used for early modern wind turbines. The classification shows the geometric profile of a NACA airfoil where the 1st digit refers to the maximum chamber to chord ratio, the 2nd digit is the camber position in tenths of the chord, and the 3rd & 4th digits are the maximum thickness to chord ratio in percent. The emergence of wind turbine-specific airfoils such as the Delft University, LS, SERI-NREL, and FFA, and RISO now provide alternatives specifically tailored to the needs of the wind turbine industry.

The angle of attack is the angle of the incoming current relative to the line of the chord and all figures for CL and CD are quoted corresponding to this angle. Using a single airfoil for the entire blade length will result in improper design [19]. Each part of the blade has different corresponding air velocity and structural requirements and therefore its airfoil section should be designed accordingly. Basically, the blade sections have a minimum thickness, which is required for dense loads created for thick profiles. Achieving a mix of tip blades in thin sections with low load, high linear velocity, and increasing critical aerodynamic efficiency Considering the airflow velocity and structural loads, different airfoil requirements related to the blade area are clear.

The aerodynamic phenomenon known as stall should be carefully considered in turbine blade design. Depending on the airfoil design the stall is usually found at a larger angle of attack. As the flow increases rapidly on the upper surface, the lift decreases, and the drag forces increase. This condition is considered dangerous in aviation and is generally avoided. However, for wind turbines, it can be used to limit the maximum energy output so as to prevent generator overload and excessive power in the blades at high wind speeds and can also occur unintentionally between gusts. It is therefore preferable that the onset of stall position is not quick for wind turbine airfoil as this creates highly moving power and vibration.

The sensitivity of the blade to the soil, the stall for structural purposes, and the design of conditions with thick cross-sections are the main driving forces for the development of wind turbine-specific airfoil profiles. The use of modern materials with excellent mechanical properties can allow thin structural sections with an increased lift to drag the proportions in the original section. Thinner sections also offer the opportunity to increase efficiency by reducing drag. High lift coefficients of thin airfoil sections result in reduced material consumption and reduce the length of the chord.

IV. CALCULATION

thickness	At %	Camber	At %	point
12%	29.10	4%	39.50	99

Table 1: NACA 4412 Airfoil parameter

Calculation of Power Density of Wind (Power) Ideal Power density of air (15 meter height is considered) consider wind speed 3 m/s and radius 1 m.

= ½ × Cp x air density × Area × (velocity) ^3
= 0.5 x .41 × 1.225 × 3.14 x (3) ^3
= 21.29 Watt

1) Calculation for blade tip speed

consider λ= TSR -Tip Speed Ratio = 8

$\lambda = \frac{\text{tip speed}}{\text{wind speed}}$

v = w r
v = λ * wind speed
v = 8*3
v = 24 m/s

2) Calculation for angular speed

ω = w r
ω = v/r
ω = 24/1
ω = 24 rad /sec

3) Calculation for speed in N

$\omega = \frac{2\Pi N}{60}$

$N = \frac{\omega * 60}{2\Pi}$

$N = \frac{24*60}{2\Pi\omega}$

N =229.18 RPM

4) Calculation For Torque

$\textbf{Pe} = \frac{2\Pi NT}{60}$

$T = \frac{Pe*60*60}{2\Pi N}$

=(21.29*60*60)/(2 ***π***229.18)

T = 53.22 N-m

5) Calculation for relative speed $=\sqrt{u^2 + v2}$

$=\sqrt{3^2 + 24\text{^}2}$

V r=24.18 m/s

Density of air ϱ = 1.225 kg/m3

Angle of attack 'α' = 6

From the above graph we find out the value of coefficient of drag and coefficient of lift.

Coefficient of Drag (Cd) = 0.008

Coefficient of Lift (Cl) = 1.126

Root chord length =.190 m ,
tip chord length =0.034 m

Area of blade =C *L = $\frac{0.190*.034 *1}{2}$

a=.00323 m2

6) Lift Force

Fl = Cl × ϱ × A ×(Vr^2/2)
Fl = Cl × ϱ× (C * L) × (Vr^2/2)
Fl = 1.3 × 1 × A × (24.18^2/2)
Fl = 1.303 N

7) Drag Force

Fd = Cd × ϱ× (C * L) ×(Vr^2/2)
Fd = Cd × ϱ × A ×(Vr^2/2)
Fd = 0.019 × 1.225 × (24.18^2/2)
Fd = .0092 N

8) Tangential Force Due To Lift

Consider (φ=Inflow angle =6^0)
Ft = F l * sin φ
Ft = 1.303* sin (6)
Ft l = 0.136N

B. Tangential Force Due To Drag

Ftd = F d * cos φ
Ft = 0.0091 * cos (6)
Ftd = .0091N

C. Tangential Force F1

F1 = F l * sin φ - F d * cos φ
F1 = 1.303 sin (6) -0.0091 cos (6)
F1 =0.1271 N

D. Axial Force F2

F2 = F l * cos φ - F d * sin φ
F1 = 1.303 cos (6) +0.0091sin (6)
F2 = 1.290 N

V. RESULT

A. We have work on the profile twist angle and angle of attack at different TSR with constant wind speed.

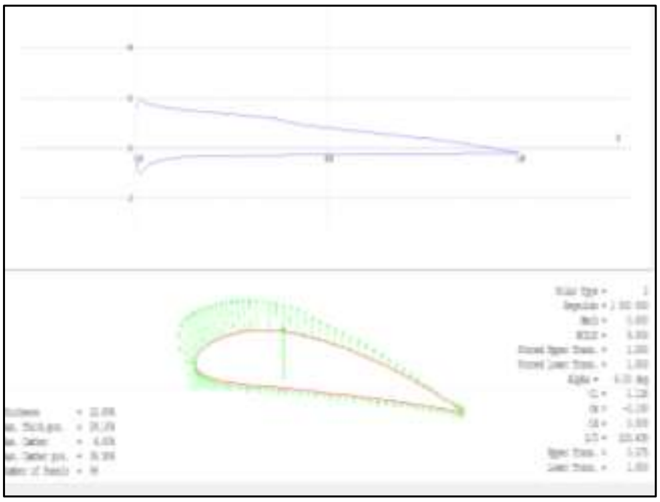

Fig. 2: aerofoil shape of blade

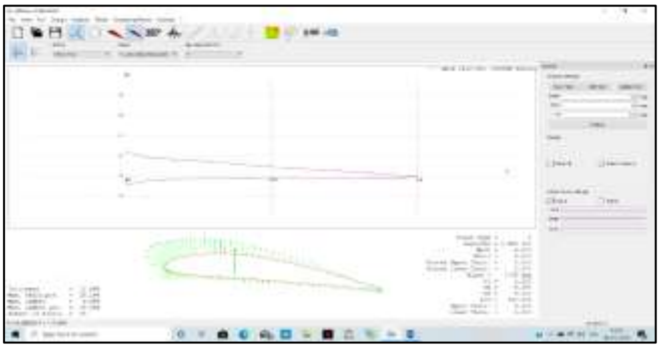

Fig. 3: L/D ratio of blade at Alpha7^{0}

Sr no.	alpha	Cl	Cm	Cd	L/D
1	5	1.021	-0.101	.008	131.72
2	6	1.126	-0.100	.008	133.63
3	7	1.223	-0.098	0.010	127.53
4	8	1.303	-0.093	0.012	111.08
5	9	1.373	-0.087	0.015	94.64
6	10	1.433	-0.079	0.015	84.91
7	11	1.490	-0.071	0.019	76.76
8	12	1.540	-0.064	0.023	67.62
9	13	1.570	-0.057	0.028	56.81
10	14	1.607	-0.051	0.034	47.92
11	15	1.628	-0.048	0.041	39.50

Table 2: Result from the analysis of blade

From the above analysis we take the result on L/D at angle of attack at 6^{0} is high and decreases with increase angle. Below 6^{0} L/D ratio decreases.

VI. Conclusion

For achieve maximum efficiency of small wind turbines at low wind speed. We selected the standard airfoil blade NACA 4412 for analysis. The parameters like angle of attack, twist angle .tip speed ratio (TSR), and chord length can affect the efficiency of wind turbines. For the better result of a small wind turbine, we choose TSR 8 for analysis and changing twist angle and focus on changing the angle of attack for high lift and drag coefficient the optimization small wind turbine blade at low wind speed. The demand for higher tip speeds reduces the width of the lower chord resulting in narrower blade profiles. This reduces the use of materials and can reduce production costs. For blades with tip speed ratios of six to nine utilizing airfoil sections with negligible drag and tip losses, Betz's momentum theory gives a good approximation input taken for design are the length of blade 1 m, chord length at root 0.191 m, at tip 0.034m, twist angle 6^{0} to 9^{0} at constant wind speed 3 m/s. If the wind is increased the performance of the design blade also increases. analysis on different angles of attack from 5^{0} to 15^{0} calculation for various angles of twist. We find maximum lift and drag coefficient ratio and angular speed 218 rpm at an angle of attack 6^{0} at TSR 8 and coefficient of power in between 0.40 to 0.45 result carried out by using Q Blade analysis software

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