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# 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 at 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 airfoil shape blade which is NACA 4412 which have a good result at a low speed we are trying to modify it profile. Comparing performance of profile NACA 4412 and NACA 63415 at different twist angle and TSR with combination of blade profile by using Q-blade analysis software.

**Keywords**: NACA 4412, NACA 63415, Q-Blade, Small Wind Turbine-Blade, Angle Of Attack.

## I. INTRODUCTION

Power has been extracted from or for hundreds of years, with historical designs made from wood, cloth and stone for the purpose of pumping water or grinding corn. Historical designs, especially large, heavy and inefficient ones, were replaced in the 1st century by the implementation of fossil fuel engines and nationally distributed energy networks. Learning more about aerodynamics and advances in materials, especially polymers, led to the return of wind energy in the late 20th century. Wind power equipment is now used to generate electricity and is commonly called wind turbines. The orientation of the shaft and rotational axis determines the first classification of the wind turbine. A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine or (HAWT). A vertical axis wind turbine (VAWT) has its shaft normal to the ground (Figure no.1.)

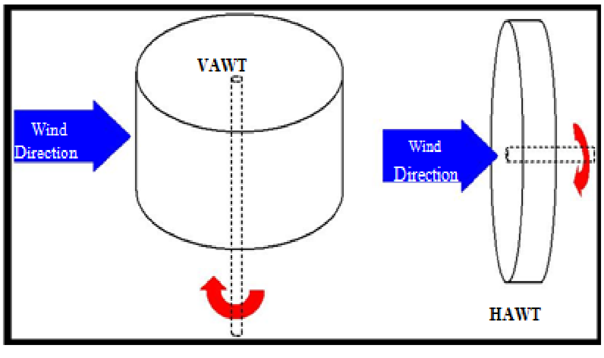


**Figure 1:** Alternative configurations for shaft and rotor orientation

The two configurations have instantly different rotor designs, each with its own favorable features. The mainstream development of VAWT can be attributed to the low tip speed ratio and difficulties in controlling the rotor speed. Difficulties in starting vertical turbines also hinder development, which is believed to have been unable to start on its own until recently However, VAWT does not require any additional systems to withstand wind and heavy generator equipment can be mounted on the ground, reducing towers. As a burden, VAWT is not completely ignored for future development. The novelty of the V-shaped VWT rotor design is currently under investigation which makes use of these favorable qualities. 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? When 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 air foil 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

Betz limit - efficiency is defined as the ratio between the power coefficient CP and the betz limit, betz = 16/27 = .593 This value was drawn by Albert Betz who was a German physicist in 1919. Converts kinetic energy into mechanical energy, so efficiency $\eta = cp / 16/27 = cp \times 27/16$. Low tip speed ratio the loss of energy for wind turbines is large, for example, if the tip speed ratio is 2 the system can achieve only 85% of the current wind turbine. The higher the tip speed ratio, the more efficient the system will be. When the tip speed ratio reaches 6, the efficiency is approximately 96%. This suggests that wind turbines with high tip speed ratios can extract more kinetic energy from the wind by comparing low tip velocity ratio wind turbines.

In our study, we are trying to improve efficiency by changing the profile, changing the angle of attack on small wind turbines on a small scale, and drawing and analyzing Q Blade software. Various parameters also help to improve the efficiency of wind turbines such as pitch angle, sweep area, camber, length of chord, angle of attack, twist, tip speed ratio, lift and drag moment coefficient, number of blades etc.

There are two great classes of wind turbines, horizontal- and vertical-axis wind turbines. Conventional wind turbines, horizontal-axis wind turbines (HAWT), spin about a horizontal axis. As the name implies, a vertical-axis wind turbine (VAWT) spins about a vertical axis. Today the most common design of wind turbine and the only kind discussed in this thesis in the view of aerodynamic behavior is the horizontal-axis wind turbines. In this chapter, detail information about the conventional horizontal-axis wind turbines will be given but before that some unconventional and innovative horizontal-axis wind turbine concepts will be mentioned.

The scope of the thesis is restricted to horizontal-axis wind turbines within two general configurations of wind turbines; namely horizontal-axis and vertical-axis wind turbines. The following sections of this chapter, however, gives an introductory remark about wind turbine; its origin, development in history, some innovative types of wind turbines, the exploration of major advantages of horizontal-axis wind turbines over all other wind turbines, technological development and use of horizontal-axis wind turbines around the world.

## II. METHODOLOGY

**Wind turbine working Principle**

All of nature's processes are an irreversible process that causes wind to flow from a high-pressure region to a low-pressure region. The change in the surface of the earth reduces the pressure. Because air has mass and it tends to form air, it has kinetic energy. Every wind generator, whether they generate enough energy to power a city or to generate electricity on a small radio, works on the same basic principles:

- The wind blows
- Blades attached to an alternator/generator experience the force of lift and begin to spin
- The generator's vane (tail) causes it to turn into the wind
- The spinning creates electricity for us to use directly or to charge batteries.

- Wind turbine working Principle
- Aerodynamic Principles of Wind Turbines
- Drag Design
- Lift Design

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- Design Key Parameter
- Wind Speed
- Site Selection
- Location
- Height
- No of Blades & Blade Length
- Generators
- Towers
- Wind Turbine Blade Material

## III. BLADE LOADS

**Introduction**

The angle of rotation with multiple air foil sections and length of chord, 22 specified stochastic load cases and numerous blade pitching angles results in complex engineering conditions. Therefore, the use of computer analysis software such as Fluid Dynamics (CFD) and Finite element (FEA) has now become commonplace in the wind turbine industry. Dedicated commercially available software for calculations based on blade geometry, tip velocity and site conditions such as LOADS, Yaw Dyne, MOSTAB, GH Bladed, SEACC and AERODYN are used. [15] To facilitate the calculation, it is suggested that the worst conditions of loading should be considered, on which all other loads can be tolerated. Worst case loading conditions depend on the size of the blade and the method of control. For small turbines without blade pitching, a 50-year storm condition would be considered a limited case. For large turbines (D > 70 m), loads caused by the mass of the blade become serious and should be considered. In practice many load cases are considered with published methods that analyze the mathematics in each IEC load case. Single governing load case analysis certification is not sufficient for modern large-scale turbine blades. Multiple load cases are therefore analyzed. The most important load cases depend on the individual design. The following loading conditions are generally preferred:

Extreme loading during operation parked 50-year storm conditions Under these operational scenarios the main sources of blade loading are listed below:

1. Aerodynamic
2. Gravitational
3. Centrifugal
4. Gyroscopic
5. Operational

**Basic Functionality:**

- Air foil generator;
- Blade design and optimization;
- Defining BEM (Blade Element Momentum);
- Multi parameter rotor simulation;
- Visualization of rotor blades;
- Blade geometry export functionality;
- Testing of aero elastic code.

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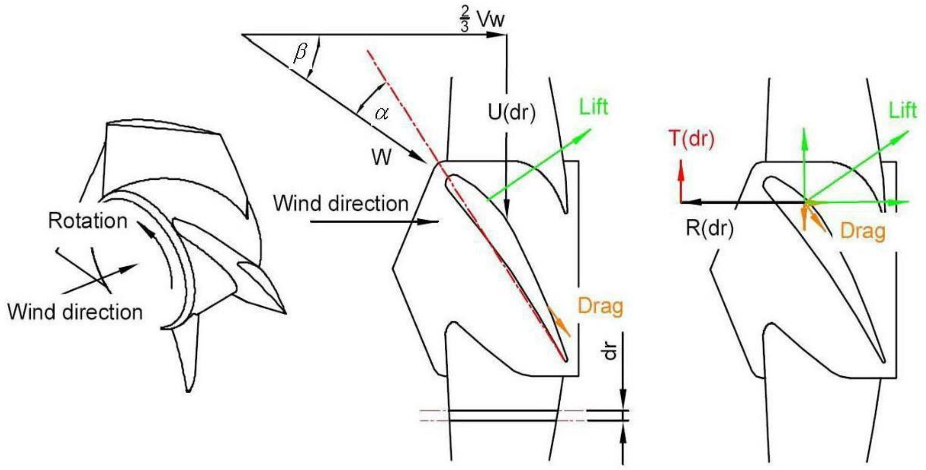


$r$ = Radius
W = Relative velocity
U($\delta r$) = Blade velocity at r
$V_w$ = Wind velocity
$\beta$ = Angle of incidence
$\alpha$ = Angle of attack
$T(\delta r)$ = Thrust at r
$R(\delta r)$ = Reaction at r

**Figure 2:** Aerodynamic forces generated at a blade element

## IV. RESULTS AND DISCUSSION

**Blade profile selection**

**Table No 1:** NACA 4412 Airfoil parameter

| Thickness | At % | Camber | At % | Point |
|---|---|---|---|---|
| 12% | 29.10 | 4% | 39.50 | 99 |

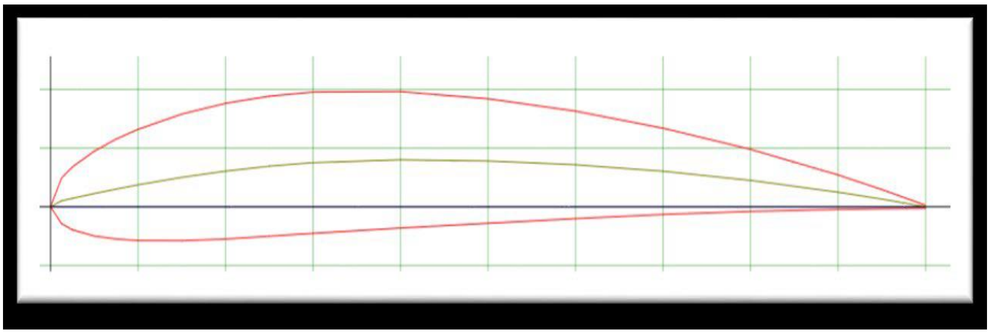

**Figure 3:** NACA 4412 profile

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 maximum chamber to chord ratio, 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 airfoil 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.

**Table No.2:** NACA 63415 Airfoil parameter

| Thickness | At % | Camber | At % | Point |
|---|---|---|---|---|
| 15% | 34.9 | 2.2% | 50 | 99 |

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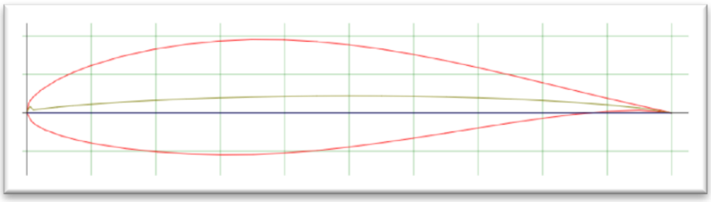

**Figure 4:** NACA 63415 profile

The NACA 63 series is chosen as the basic group for investigation because they have good low speed characteristics with a minimum compromise from consideration of the high-speed characteristics. For NACA 63 series airfoil profiles, the power curve is better in the low and medium wind speed ranges, but drops under operation at higher wind speeds. The NACA 6-series airfoil is described using six digits in the form NACA 65415 where the number "6" indicates the series. The second digit describes the distance of the minimum pressure area in tens of percent of chord. Here the area of minimum pressure is 50% of the chord back. The subscript 4 means that the drag coefficient is near its minimum value over a range of lift coefficients of 0.4 above and below the design lift coefficient, the next digit indicates the lift coefficient in tenths (here, 0.4) and the last two digits give the maximum thickness in percent chord (here, 34.9 % of chord).

**Table No.3**: Wind Blade Profile Design NACA 4412 Angle of twist 80

| NACA 4412 Angle of twist $8^0$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sr. No | Position [m] | chord Length [m] | Twist [deg] | Pitch Axis Offset [m] | Thread Axis in [% chord] | Air foil Name | 360 Polar Name |
| 1 | 0.10 | 0.05 | 0.00 | 0.00 | 0.25 | Circular Foil | CD = 1.2 360 Polar |
| 2 | 0.15 | 0.05 | 0.00 | 0.00 | 0.25 | Circular Foil | CD = 1.2 360 Polar |
| 3 | 0.20 | 0.19 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 4 | 0.30 | 0.13 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 5 | 0.40 | 0.10 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 6 | 0.50 | 0.08 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 7 | 0.60 | 0.06 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 8 | 0.70 | 0.06 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 9 | 0.80 | 0.05 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 10 | 0.90 | 0.04 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 11 | 1.00 | 0.04 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |
| 12 | 1.10 | 0.03 | 8.00 | 0.00 | 0.25 | 4412 | T1_Re1.000_M0.00_N9.0 360 |

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

$$= \frac{1}{2} \times Cp \times \text{air density} \times \text{Area} \times (\text{velocity})^3$$

$$= 0.5 \times .41 \times 1.225 \times 3.14 \times (3)^3$$

$$= 21.29 \text{ Watt}$$

Considering following data

TSR -Tip Speed Ratio ($\lambda$) = 8

Axial induction factors a = 0.39

Average chord .056 m

wind velocity (v) =3 m/s

$$u1 = (1-a)\ v = (1-.39)\ 3 = 1.83\ m/s$$
$$Vr = u1\ /\sin \varphi$$
$$Vr = 1.83\ /\ \sin (12)$$
$$Vr = 8.80\ m/s$$

Density of air ϱ = 1.225 kg/m3

Angle of attack ‘α’ = 12

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 = 0.056 *1=0.056 m2

Lift Force

$$Fl = Cl \times \varrho \times A \times (Vr\ 2/2)$$
$$Fl = Cl \times \varrho \times (C * L) \times (Vr\ 2/2)$$
$$Fl = 1.126 \times 1.225 \times .056 \times (8.80\ 2/2)$$
$$Fl = 2.99\ N$$

Drag Force

$$Fd = Cd \times \varrho \times (C * L) \times (Vr\ 2/2)$$
$$Fd = Cd \times \varrho \times A \times (Vr\ 2/2)$$
$$Fd = 0.008 \times 1.225 \times 0.056 \times (8.80\ 2/2)$$
$$Fd = 0.0212\ N$$

Tangential Force Due to Lift

Consider (Inflow angle =120)

$$Ft = F\ l * \sin \varphi$$
$$Ft = 2.99 * \sin (12)$$
$$Ft\ l = .62\ N$$

Tangential Force Due to Drag

$$Ftd = F\ d * \cos \varphi$$
$$Ft = 0.0212 * \cos (12)$$
$$Ftd = .020N$$

Tangential Force F1

$$F1 = F\ l * \sin \varphi - F\ d * \cos \varphi$$
$$F1 = 2.99 \sin (12) - 0.0212 \cos (12)$$
$$F1 = 0.60\ N$$

Axial Force F2

$$F2 = F\ l * \cos \varphi - F\ d * \sin \varphi$$
$$F1 = 2.99 \cos (12) + 0.0212 \sin (12)$$
$$F2 = 2.92\ N$$
$$A = \Pi r2$$
$$V = \Pi r2 * w$$

w – width of swept area

Density of air ϱ = 1.225 kg/m3

D/W = 1/0.19 =5.26

Mass of air = Volume of air * Density of air ϱ

V air = Πr2 *w

=3.14 (1)2(0.19)

= 0.59 m3

Mass of air = Volume of air * Density of air ϱ

M air = 0.59 *1.225

Mair = 0.73 kg

(v – v f) v f

v= 3 m/s

Angle of attack = 12 0

vf= v cos (α)

vf= 3* cos (12)

vf= 2.93 m/s

T = M air * (v - vf) vf * (d/w)

T = 0.73 *(3-2.93)2.93 *5.26

T =2.30 N-m (@ v = 3 m/s)

While simulating the blade design in Q-Blade software, first of all NACA profiles were declared as shown in Fig. 3. After that the CL/CD versus angle of Attack graphs of each section of blade was simulated. Fig.4 shows the CL/CD versus Angle of Attack graphs for 5th section of blade. The maximum value of Cl/Cd occurred for 5th section and it was equal to 140 at α=60. For other section this value was decreased and minimum value occurred for 17th section and it was equal to 100 at α=60. The power coefficient versus tip speed ratio graph was obtained by Q-blade simulation and is shown in Fig. 5. Power vs Wind Speed graph in Q-blade simulation is shown in Fig. 6. The theoretical calculation revealed a power output value of 21.29 W at 3 m/s wind speed. The Q-blade simulation results give slightly higher power output of 24 W. The power difference between theoretical and simulated design is small for minimum wind speed of 3 m/s. On the other hand, the power difference between theoretical and simulated design is significant for maximum wind speed of 3 m/s, this is due to the fact that for simulated design, the Q-blade software uses BEM theory for optimization of the wind blade which changes power coefficient to 0.47.

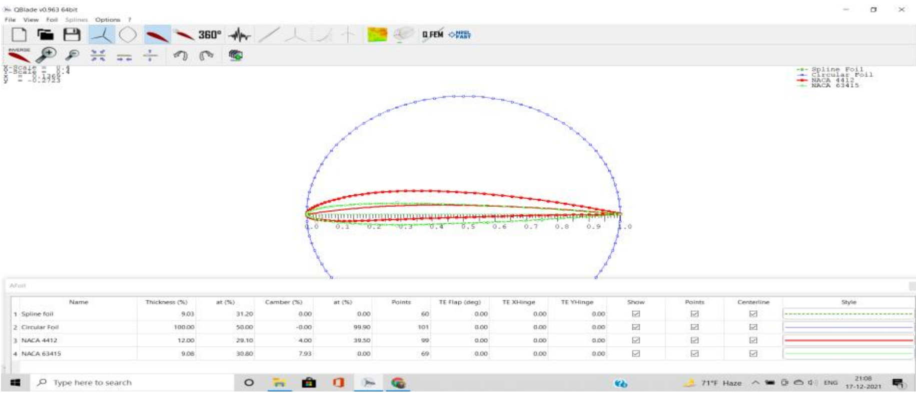

**Figure 5:** Airfoil Profile of NACA 4412, NACA 63415

**Table No.4:** Cl/Cd ratio with different angle of NACA 4412 and NACA 63415

| NACA 63415 | | | | | |
|---|---|---|---|---|---|
| Sr. No. | Alpha | Cl | Cm | Cd | Cl/Cd |
| 1 | 4 | 0.48 | -0.009 | 0.008 | 59.101 |

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| | | | | | |
|---|---|---|---|---|---|
| 2 | 5 | 0.622 | -0.014 | 0.009 | 67.479 |
| 3 | 6 | 0.73 | -0.014 | 0.01 | 73.375 |
| 4 | 7 | 0.818 | -0.009 | 0.11 | 75.216 |
| 5 | 8 | 0.905 | -0.005 | 0.012 | 75.222 |
| 6 | 9 | 0.984 | 0.001 | 0.014 | 69.514 |
| 7 | 10 | 1.062 | 0.007 | 0.016 | 64.78 |
| 8 | 11 | 1.123 | 0.015 | 0.02 | 54.957 |
| 9 | 12 | 1.147 | 0.027 | 0.27 | 42.092 |
| 10 | 13 | 1.097 | 0.04 | 0.038 | 29.006 |

| NACA 4412 | | | | | |
|---|---|---|---|---|---|
| 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 |

This paper presents the design and optimization of the rotor of the horizontal axis wind turbine blade at the lower values of operating wind speed based on blade element momentum theory (BEM) using Q Blade software. A 6 different sections of 1.1m blade length were used based on the results of the optimization of the twist angle and chord length of the blade. In order to demonstrate the computation procedures and results, NACA 4412 and NACA63415 air foil shape was chosen. NACA 4412 It was found that the maximum value of (CL/CD) can be obtained when the angle of attack (α) is 6 °to $8^0$. Also, it was found that the optimum performance of the rotor occurred when the tip speed ratio is equal 6 to 8.

**Table No.5**: Result of Power and Cp at various twist angle and airfoil

| Sr. No. | blade size | Twist angle degree | Power kw | Cp | Velocity m/s |
|---|---|---|---|---|---|
| 1 | NACA 4412 | 6 | 0.0243 | 0.386 | |
| 2 | NACA 4412 AND NACA 63415 | 6 | 0.0171 | 0.27 | |
| 3 | NACA 4412 AND NACA 63415 | 10 | 0.0309 | 0.491 | |
| 4 | NACA 4412 AND NACA 63415 | 15 | 0.0307 | 0.48 | 3 |
| 5 | NACA 4412 | 10 | 0.0372 | 0.481 | |
| 6 | NACA 4412 | 8 | 0.026 | 0.428 | |
| 7 | NACA 63415 | 8 | 0.019 | 0.306 | |

The blade axial induction factor is an important measure of performance of blade. It is a measure of the axial loading on the blade. It also helps calculating, power, thrust, torque on the rotor. It is a multi-parameter curve.

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The bold curve shows the axial induction factor for TSR 8. Curves lower to it represents induction factor for lower TSR and vice versa.

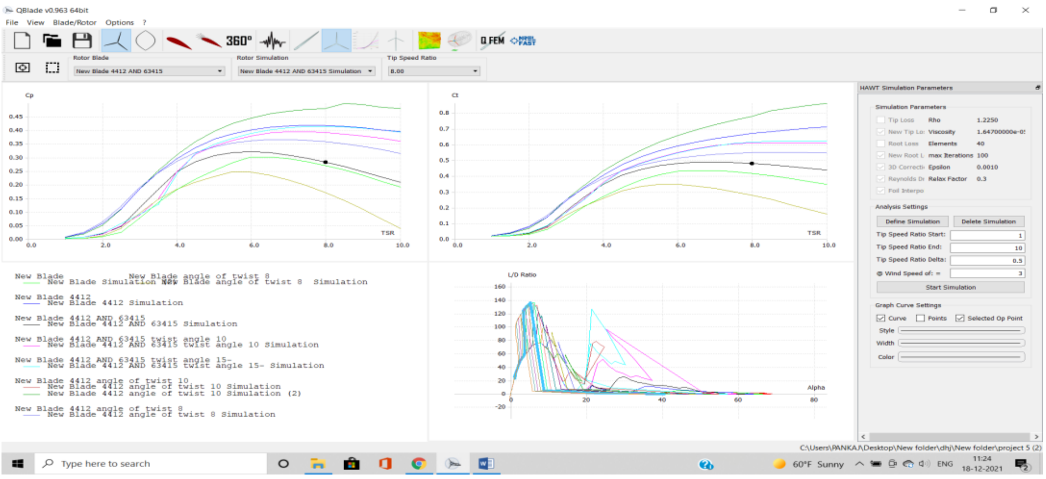


**Figure 6:** Cp vs TSR, Ct vs TSR, L/D vs alpha, at TSR 8

**Table No.6:** Result of Structural load on blade

| Sr. No. | blade size | Twist angle degree | Power kw | Cp | Velocity m/s | Mass in kg | Structural load M pa | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | blue | red |
| 1 | NACA 4412 | 6 | 0.0243 | 0.386 | | 1.00 Kg | -0.26 | 5.62 |
| 2 | NACA 4412 AND NACA 63415 | 6 | 0.0171 | 0.27 | | 1 .00 kg | -0.21 | 0.95 |
| 3 | NACA 4412 AND NACA 63415 | 10 | 0.0309 | 0.491 | | 1.00 kg | -0.31 | 3.37 |
| 4 | NACA 4412 AND NACA 63415 | 15 | 0.0307 | 0.48 | 3 | 1.00 kg | -0.1 | 3.79 |
| 5 | NACA 4412 | 10 | 0.0302 | 0.59 | | 1.00 kg | -0.47 | 10.73 |
| 6 | NACA 4412 | 8 | 0.026 | 0.428 | | 1.00 kg | -0.41 | 0.97 |
| 7 | NACA 63415 | 8 | 0.019 | 0.306 | | .92 kg | -0.22 | 0.52 |

**Power coefficient Vs Tip Speed Ratio [λ]**

Currently available commercial small wind turbines have coefficient of power in the range of 0.2-0.3. Significantly less than coefficient of power measured in large scale wind turbines which have high power generation capacity. Value of coefficient of power in wind turbines is mainly dependent on the rotor blade profile. NACA 4412 and NACA 63415 airfoil is used for rotor blade design. Blade profile can be further optimized to increase the power coefficient. Power coefficient is maximized to value 0.49 for tip speed ratios 6 to 8, We get better result on mixed profile NACA 4412 and NACA 63415 at twist angle $10^0$ at lowest speed 3 m/s

**Power [P] Vs Tip Speed Ratio [λ]**

Rotor blades have optimal tip speed ratio designed, at which they will produce maximum power. Power generated by a wind turbine is proportional to the air mass lifted/ raised by the rotor blades in given time. An increase in tip speed ratio results in decrease in the mass being lifted and affects the power output. The power curve in the Figure 7.20 shows the correlation between power output and TSR and power output reaches its maximum values for tip speed ratios of 6 to 8 of mixed blade NACA4412 and NACA 63415. It is intended that wind turbine be operated in that range of tip speed ratios for maintaining high power output.

## V. CONCLUSION

To achieve maximum efficiency of small wind turbine at low wind speed. We selected the standard air foil blade NACA 4412 for analysis. The parameter like angle of attack, twist angle. tip speed ratio (TSR) and chord length can affect the efficiencies of wind turbine. For the better result of small wind turbine, we choose TSR 8 for analysis and changing twist angle and focus on changed 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 6 to 8 utilizing air foil sections with negligible drag and tip losses, Betz's momentum theory gives a good approximation input taken for design are length of blade 1 m, chord length at root 0.191 m, at tip 0.034m, twist angle 6 0 ,8 0 ,10 0 and 15 0 at constant wind speed 3 m/s. If wind is increases performance of design blade also increases. Analysis on different angle of attack from 4 0 to 12 0 calculations for various angles of twist We find maximum lift and drag confident ratio and angular speed 218 rpm at an angle of attack 60 for NAACA 4412 and Maximum lift and drag coefficient at an angle of attack 80 at TSR 6 to 8 and coefficient of power in between 0.42 to 0.48 result carried out by using Q Blade analysis software. Rotor blades of wind turbine were designed to improve the performance and utility of small wind turbine systems. The design proposed in this paper incorporates NACA 4412 air foils due to its surface pressure distribution characteristics. This enhances the performance of wind turbines at lower speeds. Rotor blade geometry is studied and design is developed in Q-Blade software. Based on the design and simulations performed, following conclusions are obtained:

- The torque of the rotor for different wind speeds are investigated by varying blade quantity. It is observed that turbines with higher the number of blades result in better torque in low wind speed conditions. Torque is important for the turbine to be self-starting and to operate as standalone system. The drawback of high number of blades is heavy drag force generated. The limitation of self-starting ability in case of wind turbine can be overcome by incorporating hybrid drag type rotor blade design.
- The number of blades affects the TSR and produced by the wind turbine. Three blades are optimal to achieve stable power coefficient.
- Properly designed rotor blade with optimized dimensions can be used to increase the lift coefficient.
- For the blade design presented in this paper, Cl/ Cd ratio is maximised for angle of attack of 60 to 80
- As the power generated by a wind turbine is proportional to the air mass lifted/ raised by the rotor blades in given time, with increase in lift coefficient, power generation increases.
- Mixed NACA 4412 and NACA 63415 Blade profile is optimised to increase the power coefficient. Power coefficient is maximised to value 0.48 for tip speed ratios 6 to 8.

This project presents the design and optimization of the rotor of the horizontal axis wind turbine blade at the lower values of operating wind speed based on blade element momentum theory (BEM) using Q Blade software. A 6 different sections of 1.1 m blade length were used based on the results of the optimization of the twist angle and chord length of the blade. In order to demonstrate the computation procedures and results, NACA 4412, NACA 63415 and its mixed airfoil shape was chosen. It was found that the maximum value of (CL/CD) can be obtained when the angle of attack (α) is equal to 6°. Also, it was found that the optimum performance of the rotor occurred when the tip speed ratio is equal 6 to 8 at low wind speed 3 m/s

The reason of different section selection was different conditions in root, mid and tip of the blade like Reynolds number, relative wind angle, axial induction factor etc. Considering airfoils designed for wind turbines, the best airfoils with the best attack angles were selected for each section. This research showed despite two sections were selected across the blade, of two airfoil and 40 to 120 attack angles were selected for all sections. Comparing blades of different turbines shows this result is deduced in all of them. Although this result may not be satisfying at the first time, comparing this information with results of optimization of small scale wind

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turbine blades with exactly same sectioning method where two different airfoils were selected across the blade shows in small scale blades and in assumed wind condition.

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