Design and CFD analysis of Horizontal Axis Wind Turbine Blade with Microtab

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Abstract. In the design part of the wind turbine, the blade designing and its aerodynamics play a vital role. The structural analysis and optimisation of these wind blades increase the performance of wind energy. Most importantly, the designing of the wind turbine blade in the Horizontal Axis Wind Turbine (HAWT) are reviewed in this work. Also, the modern wind blade aerodynamic design principles are elaborated along with blade plan size, shape and aerofoil structure profiles. Different airfoil profiles are chosen for modelling of the wind blade to increase the co-efficient of lift generated. The review produces a trial design of the blade and stress distribution analysis is performed on the wind blade for different materials of the blade. This is modelled and analysed by the CATIA and ANSYS software. The concept of Micro tabs are familiar for airfoils used in aircraft wings to control both lift and drag generated on the airfoil. The usage of Micro tabs on wind blades is analysed. The pressure, velocity and turbulence kinetic energy acting on the blade surfaces are entirely studied. This review also provides a new concept of double micro tabs that are arranged on the pressure side of the airfoil structure, which increases lift at lower angles of attack and low wind velocity. Furthermore, the ideal positioning of micro tabs determined for single and double micro tab blade design. A comparison study is produced to determine the flow characteristic of blades with and without micro tabs.

1. Introduction
As global warming increases, so does the return on investment in wind power, because the available energy increases accordingly. Solar, on the other hand, loses energy, because of increased cloud cover, and solar cells decrease in efficiency as temperatures go up. Winds do often blow at night while solar does not work at night, so more energy must be collected and stored to balance out demand. Wind power has a very high energy density per volume of space occupied by it. If you choose a location with consistent wind, then you would require fewer power plants needed to make up for times with low winds. Unfortunately, the wind is not always steady, so one must plan to store energy or somehow have backup resources to meet that demand. When a wind-farm is producing, it’s producing a remarkable amount of energy. And it’s producing energy from something that no one wants: wind. The best locations for wind farms are typically far from population centres. Wind over a farm can help plants grow, and keep them from freezing. Wind energy can deliver a fair amount of electrical power, space-efficient, cost-effective and a massive source of energy. Also, they provide electric power from renewable means with a negligible carbon footprint. The technology is now at such a stage that the blades don't fall off as easy as they used to do. Using composites contributes to this. Disadvantages are
expensive and challenging maintenance, particularly for offshore wind installations. But the main problem is intermittency in the wind and thus wind generation. These require that backup generation or power storage is present on the grid to offset times when wind generation is low.

Pabut O et al., [1] studied on small wind turbine blade and its structural analysis, authors, also developed wind turbine blade made out of glass fibre reinforced plastic (GFRP) and validated utilising simplified finite element analysis model. They developed the 3D virtual model of blade using ANSYS Workbench software by considering all the load and boundary conditions. Various tensile tests were conducted on the GFRP and results were obtained through finite element analysis; the obtained results are validated utilising the experimentation on fabricated design with SigLab Model 20-22A. The authors concluded the characteristics, strength and the stiffness of the turbine blade could be studied using skin layout in FEA with simplified representation, which is also convenient to understand the blade lower natural frequency. Arvind Singh Rathore, et al., [2] developed a mathematical model for HAWT of 750kW with an optimal rotor design. The authors considered 21 m length blade and S809 airfoil for the blade, which is same from top to root. TAPS 2000 design is modelled, where all the loads due to inertia and wind are transferred from blades to hub. Also, by utilising finite element analysis, the loads, deflections and stresses at hubs and blades are calculated and validated with the existing design. The authors attained 0.69433 maximum deflection which is obtained at blades roots. The deflection obtained is more than the deflection in analysis by 2.2 mm in hexagonal rotor. The maximum stress obtained is 81.13 MPa which is less than the stress obtained in analysis by with 98.5 MPa of hexagonal rotor, which is developed at hub and blade flange intersection. Grant Ingram [3] studied on wind turbine blades and its available calculation methods which is easily understandable and can be utilised for either new design or existing blade analysis. The author's used blade element momentum theory for completing the design, which includes drag ad lift curves of the aerofoil. Blade Element Momentum Theory examines wind turbine operation in two methods. In the first method utilising momentum balance, the rotating annular stream of the tube passing through a turbine is calculated. In the second method the calculation of the forces generated due to aerofoil's drag coefficients and lift coefficients along the side of the blade is carried. Then series of equations are generated utilising these two methods which can be solved iteratively. Nitin Tenguria, et al., [4] studied on designing and analysis of blade in HAWT based on flap-wise loading. They developed a blade by utilising Glauert’s optimal rotor theory of 38.95 metres length for V82-1.65 MW HAWT, which depends on thickness, chord and twist for the dimensions of the blade. They considered NACA 634-221 airfoil from tip to the root. The spar and the blade are built up of some composite materials which is from tip to the root of the blade. ANSYS is utilised for the analysing the blade which is of two-fold, the transition segment and the root segment. Also, the results were validated with the experimental data.

Vipin Kumar Singh et al., [5] reviewed on design, composite material utilised to fabricate, spars, structural loads and available profiles of blade to get more efficiency rates. They identified the efficiency increases with increase in the sweep area, which increases with the area of the blade, which leads to an increment of blade length. As it also leads to an increment of mass and cost of fabrication. The authors observed the mass of the blade plays a crucial part, where the mass can be reduced by utilising the appropriate profile, spar, design, shape and material of the blade. They concluded that weight and length are the influencing factors to increase the efficiency, strength and stability of the wind turbine blade. Prabaharan Elangovan [6] analysed on the wind turbine blades and its fluttering behaviour. The fluttering in the blade occurs due to increase in amplitude of rotation, material damping, air-blade mass ratio, an aspect ratio of blade, the aerodynamic centre is different from centre of mass, high tip speeds, low stiffness which leads to vibrations in the turbine causes loss of control in blade, damage of the blade structure. It is examined utilising model and structural analysis. For the wind turbine blade to aeroelastic stability analysis is carried out. To understand its stability range. ANSYS workbench is utilised for the study of the blade structure. They concluded for higher efficiency rate, and less fluttering of blade high torsional stiffness is required. Peter J. Schubel et al., [7] reviewed how blade loads, blade design, propulsion increase the efficiency of the wind turbine.
system. They compared the theoretical and practical effectiveness of HAWT. The authors observed horizontal axis rotors mostly utilised in all wind turbines in the current scenario. They described the operational, gyroscopic, centrifugal, gravitational and aerodynamic principles of designing the blade, which includes blade angles, aerofoil sections, quantity, shape, size, plan. They concluded a little change in the shape of blade with new tip designs, aerofoils and structured materials have high efficiency, as the larger the size of the blade more problematic they are in terms of installation, cost, maintenance and so on. Scott J. Johnson et al., [8] studied on control of the wind turbine, and available techniques can be used for it. This control mainly on either the smart rotor control or smart structures, which focuses on actuators. The current turbines depend on the actuators and sensors for better controlling. As for increasing the power output the turbine is increased which leads to a reduction in the life span of the turbine and requires larger rotors for rotating and leads to increase the maintenance cost. Also, larger rotor loads cause fatigue and structural loadings. So new load control systems like are utilised which have controlled speed, lightweight and small in size with improved performance, turbine life, high energy collection and reduction in materials.

As the development of wind turbines over the last few decades could be grouped into four categories: Aerodynamic principals: moving from drag principal to lift principal; Design type: from vertical to horizontal axis design; Machine size: rotor size and hub height increment which leads to high rated power output; and Location: moving offshore. The wind turbine converts kinetic energy in the wind (moving air particles) to useful mechanical energy (a rotating shaft driving a generator). The lift principle is more efficient, and all modern wind turbines work on this principle. Horizontal axis designs are the most efficient and since they have a higher efficiency rate. Bigger machines result in more power because a larger rotor has a larger swept area (more wind) and higher hub heights mean higher wind speeds. The power output of a wind turbine is proportional to the square of the rotor radius (P ~ R^2). This means if the rotor radius is doubled, the power output can be increased by four times. Also, the mass of the blade is proportional to the cube of the rotor radius (m ~ R^3). This means that if the radius is doubled, the power output may be 4x, but 8x the mass.

Scaling up the size without limits is therefore not possible. You can imagine that is brings about a bunch of structural issues that all cost money to solve. The benefit of offshore is simply that there is a lot of wind. The drawback is that the construction is trickier and more expensive. And once the things are out there, one has to do maintenance and repairs, etc. which is not so easily done. Besides the noticeable improvements in areas such as manufacturing procedures and economies of scale, making them bigger is the easiest way (and maybe the only way) to make the technology more cost-effective. This holds until one hit the limits of what is structurally possible with foundations, towers and connections between the blades and the hubs.

Is wind energy the future? There are so many variables and perspectives that without touching on them, it is very tough to answer this one. It requires a good understanding of the country resource availability, its needs, current technology, prices, geopolitics etc. Where India has become a decent wind resource, and we need to add wind capacity. Of the 26GW of renewable capacity that India has installed 18GW is wind energy. It is growing at 15-20% a year and is expected to for the next few years. There are major problems with the uptake of wind energy: mainly price, policy support and grid integration. Today, we can achieve higher hub heights and bigger diameters to capture more wind and hence more generation, resulting in internationally falling wind prices. But with increasing coal prices and improving wind technology, relatively stable wind prices, a cross over point is expected in future where the uptake of wind capacity will be easier. Integrating wind power into the grid is not easy without sound forecasting systems in place. The wind is a good option and has a good. Recently the wind potential was upgraded from 48GW to 100GW. Now India is already the world's fifth largest wind energy producer. Wind energy currently constitutes 70% of India's total renewable energy production. Enhancing wind power generation capacity in India is one of the primary objectives that fall under renewable energy initiatives.
2. Methodology

![Diagram of methodology]

**Figure 1.** Methodology followed for this work.

3. Results and Discussion

3.1 Results from the Deformation Analysis.

With all four materials GFRP, steel, aluminium, sisal carrying equal loads at equal sections as to other, the basic analogy is for the deformation to be minimum at the position of the blade entitled towards the rotor and maximum at the profile converging outwards away from the rotor. Further the as of loads, deformation gradually increases in even arithmetic progression for the composites and fibres. The minimum deformation occurrence at the rotor for a fibre material is more than the maximum deformation of that of steel material. Simultaneously, the aluminium material carries deformation very low similar to that of steel. On the other hand, the sisal fibre causes the maximum deformation throughout the uniformly loaded wind blade and at the tip of the blade. The analysis was repeated with the change in the load acting on the blade, keeping uniform loading as constant. The results were drawn the mean of the deformation occurrence and are consolidated specifically at the loading edge of the wind blade, at the tip away from the rotor where maximum deformation on the blade occurs.

| Material  | Total Deformation | Result(mm) |
|-----------|-------------------|------------|
| GFRP      |                   | 0.24062    |
| Steel     |                   | 0.012487   |
| Aluminium |                   | 0.035677   |
| Sisal     |                   | 0.43008    |

3.2 Stress and Strain Analysis on the Blade for Different Materials.

The details of stress and strain analysis for the different materials performed in ANSYS are drawn and compared. The stress and strain analysis were carried after the nodes were set. To cut, or divide the specimen and integrate the actual stress in the direction of loading. To repeat the analysis in 3 distinct locations only to obtain similar results due to the equilibrium. The positioning is varied to consider any
numerical inaccuracies. The average result was drawn after repetitive tests with change in loads at each one of these three distinct locations, and further to calculate strain from these average displacements.

| Material  | Strain Analysis Result | Stress Analysis Result |
|-----------|------------------------|------------------------|
| GFRP      | 1.6889E-5              | 0.23876 MPa            |
| Steel     | 8.3048E-7              | 0.15675 MPa            |
| Aluminium | 2.3278E-6              | 0.15675 MPa            |
| Sisal     | 2.6948E-5              | 0.07428 MPa            |

3.3  Analysis for Blade with Single Micro Tab.

With the finalise base design, introduction of Microtabs at various positions are been made and in-depth analysis of Pressure distribution, velocity contour and maximum turbulence energy powered are done using ANSYS and results are consolidating accordingly. From the results obtained, it is clear that the Wind blade with the micro tab placed 15cm from the trailing edge would provide more stability and high co-efficient of lift. For any wind blade airfoil structure, the increase in pressure at the bottom surface of the blade near the leading edge will create pressure difference at the wake of the blade to generate lift. Also, from the velocity contour it is determined that the flow characteristic is improved by moving the tab a little upstream from the trailing edge. Hence it is determined that the micro tab is ideally positioned at 0.34 percent - 1.03 percent of the chord length of the blade from the trailing edge of the wind blade.
### Table 3. Analysis for blade with single micro tab.

| Single Microtab Position from Trailing Edge (cm) | Maximum Pressure Distribution (Pa) | Maximum Turbulence Kinetic energy (J/Kg) | Velocity Contour (m/s) |
|------------------------------------------------|-----------------------------------|-----------------------------------------|-----------------------|
| 5                                               | 8.54E-5                           | 2.608                                   | 1.835E+4              |
| 10                                              | 1.256E+2                          | 7.111                                   | 1.802E+1              |
| 15                                              | 1.282E+2                          | 14.81                                   | 1.808E+1              |

#### 3.4 Analysis for Blade with Double Micro Tab

After analysing single micro tab, we introduced 2 micro tabs at different positions each satisfying the aerodynamics of the wind blade and proceeded with the analysis of Maximum pressure distribution and Maximum turbulence energy powered and drew the following results. From the results obtained from the analysis of wind blade with double micro tabs, we can conclude that the blade design with micro tabs 100cm apart from each other will produce greater power in shorter periods of time due to the high lift generated. The tabs for double micro tab blade design are spaced equally from the centre of the chord line. The analysis shows that higher turbulence kinetic energy is produced between the tabs and at the wake of the blade when the distance between tab is increased, due to which air circulation pockets are created. These help in lifting the airfoil structure at low angles of attack when the wind moves out through the wake of the wind blade.

![Figure 3](file.png)

**Figure 3.** Analysis of Double micro tab (a) Pressure Distribution (b) Turbulence kinetic Energy at 25cm, 50cm, 100cm from Trailing edge.

### Table 4. Analysis for blade with double micro tab.

| Distance between the 2 Microtabs (cm) | Maximum Pressure Distribution (Pa) | Maximum Turbulence Kinetic energy (J/Kg) |
|--------------------------------------|-----------------------------------|-----------------------------------------|
| 25                                   | 1.309E+2                          | 2.973                                   |
| 50                                   | 1.322E+2                          | 5.845                                   |
| 100                                  | 1.244E+4                          | 4.371                                   |
3.5 Result to determine the Satisfactory Blade Design.

The study provides an insight on how changing certain aspects of a blade structure can change the output produced by the wind blade. The results are comprehended from the analysis conducted. The wind blade design with micro tabs are found to be more efficient than without them. Moreover, the wind blade with double micro tabs are determined to be the best option from the comparison result of the blade structure that can provide the parameters which are necessary to generate lift at high rates.

| Type of Blade                  | Specification                          | Maximum Pressure Distribution (Pa) | Maximum Turbulence Kinetic energy (J/Kg) |
|-------------------------------|----------------------------------------|-----------------------------------|------------------------------------------|
| Blade without micro tab       | NIL                                    | 1.044E-4                          | 5.656                                    |
| Blade with single micro tab   | Tab 15 cm from trailing edge           | 1.281E+2                          | 1.481E+1                                 |
| Blade with double micro tabs  | Tabs 100cm apart from each other       | 1.244E+4                          | 4.371                                    |

4. Conclusion

Energy has become a commodity, which means prices have to be cheap. Wind and solar are very much functional technologies, and most research is going into making the proven concept more efficient rather than coming up with something completely new. From the obtained results, it is concluded as follows, the wind blade with S809 profile design for the root section and NACA 4412 for the tip section provides great stability and high lift. From the materials selected to be used for this wind blade, GFRP (E-Glass) is the most suited one for its low density, light weight and high strength. But due to the high cost of GFRP, Sisal is a viable option for smaller wind blades and a composite of Sisal and GFRP infused using epoxy resin can be used for larger blade structure to increase stability and reduce production cost. The use of Micro tabs produces greater lift and hence can produce more power in shorter period with lesser wind velocity and angle of attack. If single micro tabs are used then good efficiency is obtained when the tab is placed at 0.34percent - 1.03percent of the chord length away from the trailing edge. The blade that consists of double micro tabs are more efficient than ones with single tab or without tabs. Wind and solar photo voltaic can be combined on the same land assuming good conditions with about 1–2% shading of the solar from the wind. Grazing and farming can take place around wind turbines even with added solar in many places.

5. References

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