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Structural Design of a Wind Turbine Blade: A Review

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Abstract: Wind energy is the one of the fastest growing energy source in world; it is clean and renewable source of energy. Many researches are aimed towards designing the big size wind turbine for gaining more and more energy in minimum cost. Wind turbine blade is the most important component to produce electricity from wind. Blade is responsible for capturing the energy from wind. Thus, blade has to be designed in such a way that more and more energy can be extracted from wind, and also blade must have good strength and minimum mass. In this paper, a comprehensive review on various profiles, structural loads, spars, composite material used in design of blade is presented, and a methodology is presented for a selection of proper design profile, spars, and composite material for wind turbine blade design. The spar cap size, types, and material used has great influence in blade mass and strength. This aspect is highlighted in present paper.
Keywords: blade profile, structural loads, spars, composite material.

1. Introduction

In wind turbine, blade is very important component, as the energy extraction from wind mainly depends on the structure of blade; wind are highly variable in nature and difficult to handle and also due to lower density of air larger surface area of blade has to be needed for higher efficiency. Therefore, the design and manufacturing processes have a dispersive influence on the structural performance on the blade.

There are various methods for designing of blade profile. FEM (finite element method) based software ANSYS, BEM (blade element method), CFD (computer fluid dynamics), are some of them. CFD are used for prediction of aerodynamics and load characteristics of wind turbine blade. BEM theory is used for calculating various types of loads on the wind turbine blade. ANSYS CFX is used for analysis of various stresses producing in the blade. [1]

The blade consists of two faces (suction and pressure side) joined together by adhesives and stiffened by many shear webs (I section) or by box beam (box spar). Wind turbine blade subjected to many types of loading like flap wise and edgewise bending, gravitational forces, tensional loading as well as loads due to pitch acceleration. Edgewise bending is caused by gravitational forces and torque of blade where as flap wise bending is due wind pressure; the spar is the main component to endure the flap wise bending while edgewise bending is resisted by edges of blade. [2]

In current era, composite materials are efficiently used for blade design such as E glass fiber and carbon fiber due to their superior mechanical properties and its light weight. Due to increasing size of wind turbine blade the important issue is to arrange composite material in such a way that we use the maximum strength of material. Hence, selection of good material is very important for higher efficiency of blade. [3]

The objective of this paper is to review different profiles, loads, spars and materials of the wind turbine blade and incorporation of an efficient design methodology.

2. Mathematical Model

2.1 Blade Element Momentum Theory

This theory is mainly used to prediction of chord length and thickness of blade. It also yields efficient information about the wind load. It provides necessary information regarding aerodynamics forces and moments acting on blade. In this theory, blade is divided into different smaller elements and each element is analyzed for calculation of wind load. This theory is combination of Betz's law and the aerofoil law. The blade is subjected to an extreme wind speed, U, and the resulting lift and drag forces are dF_L and dF_D. The lift and drag forces can be defined as,

$dF_{L=} C_D \frac{1}{2} \rho U^2 C\, dr$ (1)

$dF_{D=} C_D \frac{1}{2} \rho_U{}^2 C\, dr$ (2)

Where C_L and C_D are the lift and drag coefficients, ρ is the air density, c is the chord length of the air foil, and dr is the length of the blade element. [4]

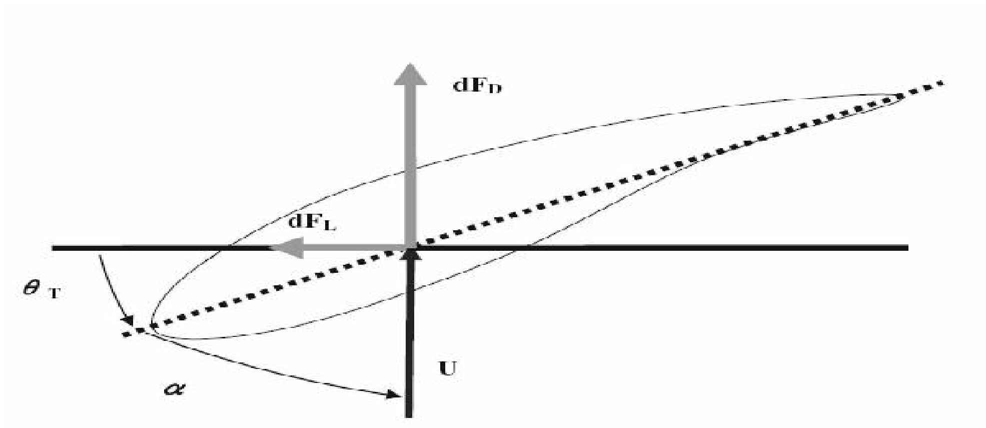

Figure 1. The cross section of a blade element under loading at the parking position

2.2 Finite element method

In this method, the whole body is divided into many small elements and all section are analyzed for the stress and loads acting on it. ANSYS CFX is used in this paper for analysis.

3. Methodology

There are different methodologies used by researchers to obtain a good design and economic performance. In this paper a proper design methodology is presented to improve efficiency and strength of wind turbine blade.

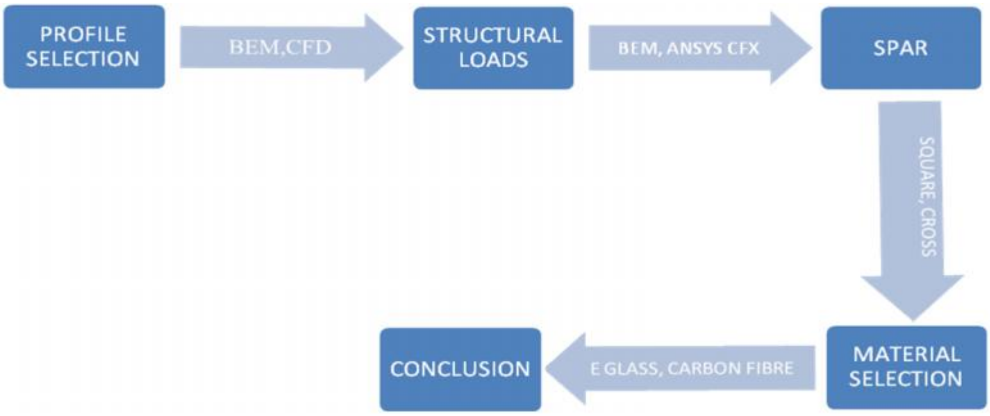

Figure 2. Step by Step Design modifications of wind turbine blade

3.1 Selection of profile

Wind turbine profile is very important aspect for the wind turbine blade. As, it is very important in the deciding the amount of aerodynamic loads, a turbine blade can withstand; it also decides the various aerodynamic aspects of the blade. Various standards are there, which set up various shapes of the blade like NACA series, SERL series etc.

Blade element momentum theory is very useful in finding out the characteristics of blade like chord length and angle of twist of a given aerofoil cross section and the speed of rotation at finite number of locations along the span of the blade. But, BEM is not entirely accurate if the data for the airfoil cross sections used are not corrected for the rotational aspects.

This is the reason, why computational fluid dynamics (CFD) is used for the analysis of a new blade design as it provides proper and accurate design. Thus, selection of profile is mainly based upon computational flow dynamics. [1]

3.2 Structural loading

BEM theory and ANSYS CFX is very useful to calculating variable types of loads on the wind turbine blade, like drag and lift forces. A direct analysis of the flow field around the turbine blade is done to observe the wind load acting on blade using ANSYS CFX and BEM theory. Both the results are compared and it was found that calculation model of CFX are more close to real case, but requires large initial data for applying boundary conditions, where as BEM theory is simple and provides value of wind loads with reasonable accuracy. Hence, BEM theory can be used effectively to calculate wind loads. [4]

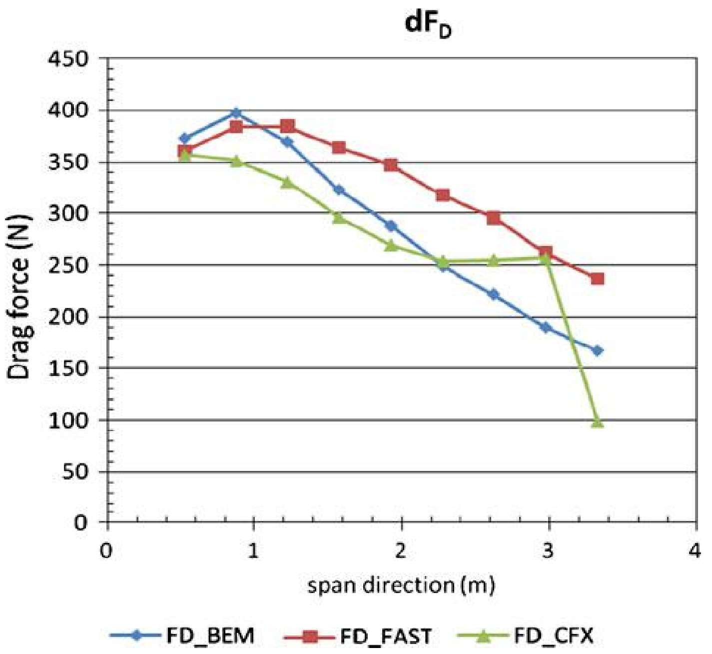

Figure 3. The drag forces calculated by the BEM, FAST and CFX

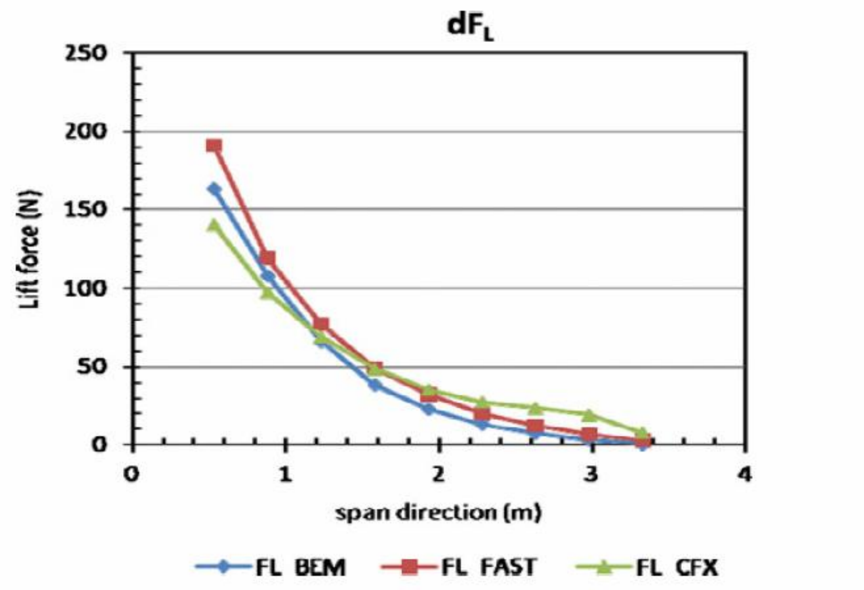

Figure 4. The lift forces calculated by the BEM, FAST and CFX

3.3 Spar

Spar cap is the main component of the blade which endures most of the force and bending moment acting on the blade; the size of a spar plays an important role in deciding blade mass and stiffness of blade and also has great influence on the strength of blade. Spars and internal webs in the blades are used to restrict the effect of flap wise bending loads while edges of the profile carry the edge wise bending loads. Spars carry the 85- 90% of the load acting on the blade, so, it is a very important and indispensible part in the wind turbine blade. Conventionally used square box girder is compared with modified spar (cross box girder). It was found that cross box spar undergoes a little less deflection then square shape spar blade. Hence, cross box spar blade may handle little more load of wind turbine blade. [2]

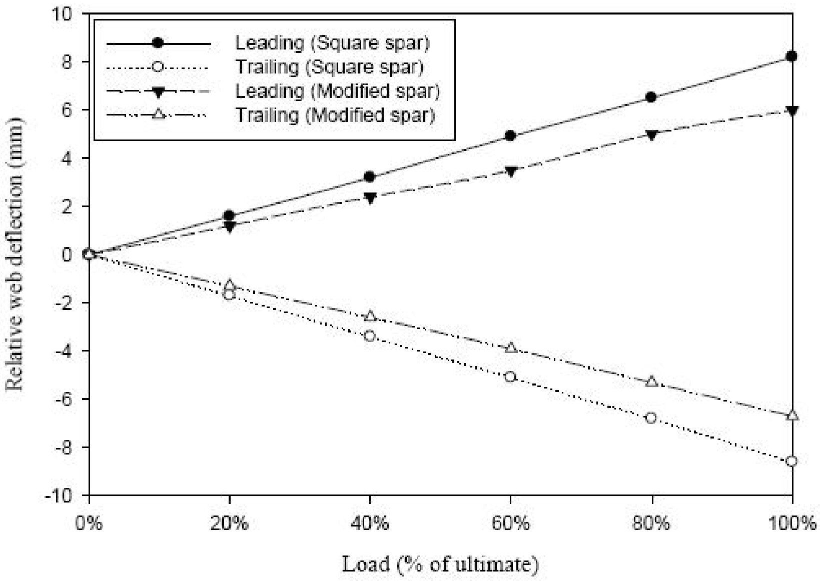

Figure 5. Comparison of Square & Modified Spars

3.4 Material selection

The durability and life of wind turbine blade can be increased, if the wind turbine blade has high stiffness, environmental loading resistance and low weight. These properties can be obtained by using advance composite material. The composite material has superior mechanical properties, lower weight and higher strength compared to many metals and alloys. In wind turbine blade long fiber reinforced polymers laminates are responsible for enduring strength and damage resistance, shape stability, while resin matrix are responsible for stiffness, fracture toughness and out of plane strength. In modern era, carbon fiber and E glass fiber material are mainly used for making blade. Carbon fiber has more promptly used in spar design comparing with E glass fiber, as it has high stiffness and density then carbon fiber. However, it has relatively lower damage tolerance, compressive strength and much more expensive. Therefore, carbon fiber is used for designing spar and E glass fiber is used for making outer periphery for good strength and lower cost of blade. [3]

4. Conclusion

This paper provides a review of methodology for designing wind turbine blade by optimizing various characteristics and parts of blade. On increasing length of blade, the swept area increases and hence, it captures more power. But, on increasing length, the mass of blade also increases which increases cost of construction. Thus, reduction of mass is a very important aspect in design of wind turbine blade which can be obtained by using proper material, proper shape and design of spar and proper selection of profile. Hence, proper methodology of design is used to synchronize length and weight, and an efficient wind turbine blade with high stability, strength with appropriate cost can be obtained.

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