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DESIGN OF WIND ENERGY TURBINE BLADES: A review

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Abstract- A review of the current status for wind turbine blade design is presented, including efficiency, propulsion, blade design, and load on blades. The aerodynamic design principles for a modern wind turbine blade are in detailed; it includes blade plan shape/quantity, aerofoil selection and optimal attack angles. This paper investigates the multidisciplinary nature of wind turbine design as it applies to turbine blades. The goal is to reduce the end unit cost of electricity, amortized over the turbine lifetime, for a particular location. In this paper, a developed methodology is used to predict the optimal performance of the horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT) in terms of the most critical parameters such as tip speed ratio, pitch angle, blade number and wind speed. Interesting generalized performance maps were conducted. Results show that low pitch is recommended for low wind speed regime.

Keywords: wind turbine; blade design; blade angle; HAWT, VAWT, aerodynamic, Efficiency.

1. INTRODUCTION-

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity. The term "wind energy" describes the process by which the wind is used to generate mechanical energy or electricity. Wind turbines convert the kinetic energy in the wind into mechanical energy. The development of wind power in India began in the 1990s, and has significantly increased in the last few years. Although a relative new comer to the wind industry compared with Denmark or the United States, India has the fifth largest installed wind power capacity in the world. In 2009-10 India's growth rate was highest among the other top four countries. Our goal is to introduce as many people as possible to the elegance of renewable energy through hands-on science activities which are challenging, engaging, and teach basic science principles.

Blade design and engineering is one of the more complicated and important aspects of current wind turbine technology. Engineers strive to design blades that extract as much energy from the wind as possible in a variety of wind speeds, while remaining durable, quiet and affordable. This engineering process requires a great deal of scientific experimentation, modeling, and testing. We can experiment with advanced concepts in wind turbine blade design, including airfoil shapes and twisted-pitch blades.

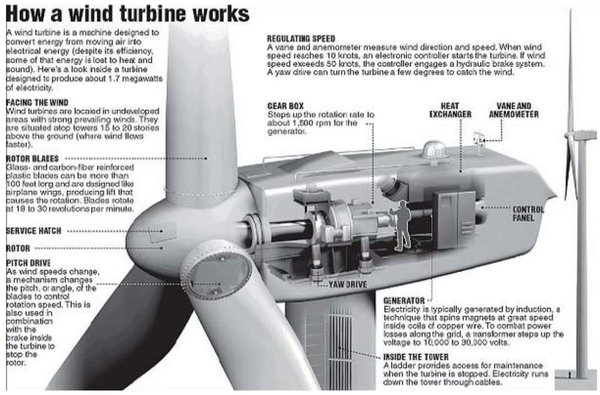

Fig. 1.1 working of wind turbine

WIND POWER-

The power in the wind can be computed by using the concepts of kinetics. The kinetic energy of any particle is given by the following formula

Kinetic Energy =½mv2.

Amount of Air passing is given by

m = ρ AV………………….. (1)

Where

m = mass of air transverse

A=area swept by the rotating blades of wind mill type generator

ρ= Density of air

V= velocity of air

Substituting this value of the mass in expression of K.E= $\frac{1}{2}\rho AV.V^2$ watts

= $\frac{1}{2}\rho AV^3$ watts………………….. (2)

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Second equation tells us that the power available is proportional to air density (1.225 kg/m^3) is proportional to the intercept area. Since the area is normally circular of diameter D in horizontal axis aero turbines, then,

$$A = 0.25\pi D^2 \text{ (Sq. m)}$$

Put this quantity in equation second then
Available wind power

$$Pa = 0.125 \rho \pi D^2 V^3 \text{ watt}$$

2. BLADE DESIGN

Blades come in many shapes and sizes, and there is continuing research into which design is best. It turns out that the optimal design really depends on the application, or where and how the blade will be used. Designers look at the "tip speed ratio" that determines efficiency. This is the ratio between the speed of the wind and the speed the blade tip. High efficiency 3-blade-turbines have tip speed/wind speed ratios of between 6 and 7.

2(a) NUMBER OF BLADES IN WIND TURBINE-

Most wind turbines use either two or three blades. Research indicates that as more blades are added there is a increase in aerodynamic efficiency, but this efficiency decreases dramatically with each added blade. For example, increasing the number of blades from one to two can yield a six percent increase in aerodynamic efficiency, but increasing the blade count from two to three yields only an extra three percent in efficiency. And, of course, there are cost implications too. Each additional blade in a design will increase the cost of the end product, so engineers have to factor in both the increased efficiency and the increased cost of manufacturing to determine a design that will be the best for an application. Aesthetics is also a consideration. A small, two or three blade design might be best for a residential area, where a homeowner just wants to pull from the wind enough energy to power their own home, and would prefer a quieter option. A giant 12 blade design would not look very nice atop their home and would perhaps generate more energy than they need and likely more noise too! To the right you can see how NASA tested a one-bladed rotor configuration.

2 (b) MATERIALS FOR BLADE IN WIND TURBINE-

Early windmills were made of wood with canvas sails. These deteriorated over time and required care – but they represented the materials readily available! More recently, older mechanical turbine blades were made out of heavy steel…but now many are made using fiberglass and other synthetic materials that offer strength at lower weights. And, lower weight building materials can result in larger blades to catch more wind in applications where size and space are less of an issue. Manufacturers also use epoxy-based composites which may offer manufacturing advantages over other materials because the process has less impact on the environment and can result in a smoother surface finish. Carbon fibers have also been identified as a cost-effective method to further reduce weight and increase stiffness. Smaller blades can be made from light metals such as aluminum. Engineers will be working in this field for years to come to determine the optimal shape, weight, and materials to generate energy most efficiently.

2 (c) SHAPE OF BLADE FOR WIND TURBINE-

Turbine blades are made in many different shapes – and sometimes it is the application that determines which shape is best. For example, a wind turbine blade design that researchers at Sandia National Laboratories developed in partnership with Knight & Carver of San Diego, CA promises to be more efficient than current designs. It should significantly reduce the cost-of-energy (COE) of wind turbines at low-wind-speed sites. Named “STAR” for Sweep Twist Adaptive Rotor, the blade has a gently curved tip, termed “sweep,” which unlike the vast majority of blades in current use, it is specially designed for low-wind-speed regions like the Midwest of the United States.

An efficient rotor blade consists of several aerofoil profiles blended at an angle of twist terminating at a circular flange. It may also include tip geometries for reducing losses. To facilitate production, several simplifications maybe made:

- Reducing the angle of twist.
- Linearization of the chord width.

Reducing the number of differing aerofoil profiles.
All manufacturing simplifications are detrimental to rotor efficiency and should be well justified.

The introduction of new molding techniques and materials has allowed the manufacture of increasingly complex blade shapes. However, the economics of production coupled with difficulty of design analysis still dictate final geometry. Leading wind turbine suppliers now include most optimization features such as angle of twist, variable chord length and multiple aerofoil geometries

Wind-turbine designers are taking their cues from fish and whales, 29 September 2011—think about and chances are that fish and whales aren’t the first things that pop into your head. But the marine is just where some researchers are looking for inspiration to improve wind energy. They’re applying the concepts of —using nature’s designs in their own—and it’s working, as evidenced by big strides in efficiency and output.

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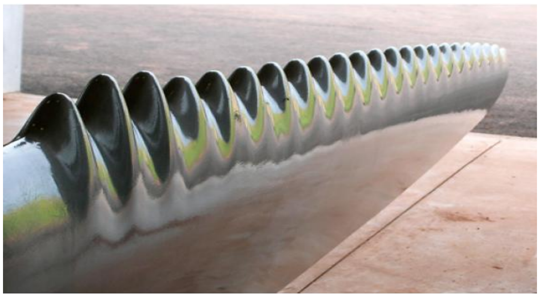


Fig. 2.1 shape of turbine blade

2 (d) WIND TURBINE AERODYNAMIC

According to the different rotational orientations, wind turbines can be categorized as vertical-axis or horizontal-axis. The advantages of vertical-axis wind turbine (VAWT) are:

1. Simple structure: VAWT can work without yaw system and most of them have a blade with constant chord and no twist (Manwell, et al., 2002, p.259), which is easy to construct.

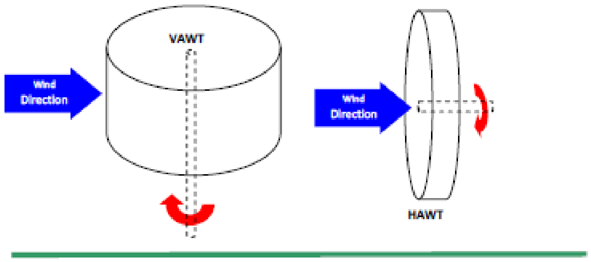
2. Easy to install: because the drive trains (gear box, brake and generator) can be located relative to the ground.

Comparing to horizontal-axis wind turbine (HAWT), stall control can only be used in VAWT as it is difficult to incorporate aerodynamics control such as variable pitch and aerodynamic brake, so the overall power efficiency is lower than HAWT.

Figure 2-2 Vertical-axis wind turbine

Figure 2-3 Horizontal-axis wind turbine

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.



2 (e) LIFT, DRAG AND MOMENT COEFFICIENTS

In general, there are two forces and one moment that act upon an aerofoil; these being lift, drag and pitching moment. The definitions of those three forces are explained in this section. Lift is the force used to overcome gravity (Hansen, 2008) and is defined to be perpendicular to direction of the oncoming airflow (Manwell, et al., 2002). It is formed as a consequence of the unequal pressure on the upper and lower airfoil surfaces. The drag force is defined as a force parallel to the direction of oncoming airflow. (Manwell, et al., 2002) The drag force is due both to viscous friction forces at the surface of the aerofoil and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow. The lift is the force used to overcome gravity and the higher the lift the higher the mass that can be lifted off the ground. For an aerofoil, (Hansen 2008) stated that the lift to drag ratio should be maximized. As a result, it can improve efficiency when wind turbine generates electricity. Lift and drag coefficients *CL* and *CD* are defined as follows.

Lift coefficient $$C_L = \frac{F_L}{1/2\rho V_0^2 c}$$

Drag coefficient $$C_D = \frac{F_D}{1/2\rho V_0^2 c}$$

Where ρ is the air density and is the length of the aerofoil, often denoted by the chord, unit for the lift and drag in Equations is force per length (in N/m).

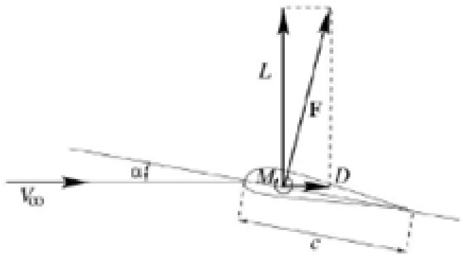


Figure 2-4 Definition of lift and drag ratio (Hansen, 2008, p. 8)

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2 (f) AERODYNAMICS OF WIND TURBINES

The airfoil is the most important and fundamental element in building a wind turbine blade. Airfoil characteristics will determine the performance of the wind turbine, expressed in terms of CT and CP. Lift coefficient and drag coefficient of airfoil are the central for designing a wind turbine and the foremost parameters to be considered. These coefficients depend on Reynolds number. In fluid dynamics, non-dimensional Reynolds number is defined as

$$Re = \frac{UL}{\nu} = \frac{\rho UL}{\mu}$$

Where μ is fluid viscosity, ρ is the fluid density, and v is the kinematic viscosity, U is the velocity of fluid passing the airfoil surface, L is the length of the flow. L will be replaced by the chord length c in terms of wind turbine blade.

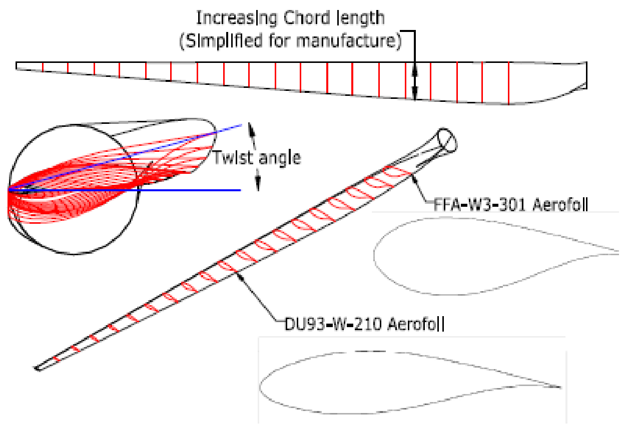

Fig. (2.5) A typical modern HAWT blade with multiple aerofoil profiles, twist and linear chord length increase.

2 (g) BLADE LOADS-

Multiple aerofoil sections and chord lengths specified stochastic load cases and an angle of twist with numerous blade pitching angles results in a complex engineering scenario. To simplify calculations, it has been suggested that a worst case loading condition be identified for consideration. The worst case loading scenario is dependent on blade size and method of control. For small turbines without blade pitching, a 50 year storm condition would be considered the limiting case. For larger turbines (*D* > 70 m), loads resulting from the mass of the blade become critical and should be considered. The most important load cases are dependent on individual designs. Typically priority is given to the following loading conditions:

- emergency stop scenario
- 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

2 (h) PROPULSION

The method of propulsion critically affects the maximum achievable efficiency of the rotor. Historically, the most commonly utilized method was drag, by utilizing a sail faced normal to the wind, relying on the drag factor (*Cd*) to produce a force in the direction of the prevailing wind. This method proved inefficient as the force and rotation of the sail correspond to the wind direction; therefore, the relative velocity of the wind is reduced as rotor speed increases (Table 1).

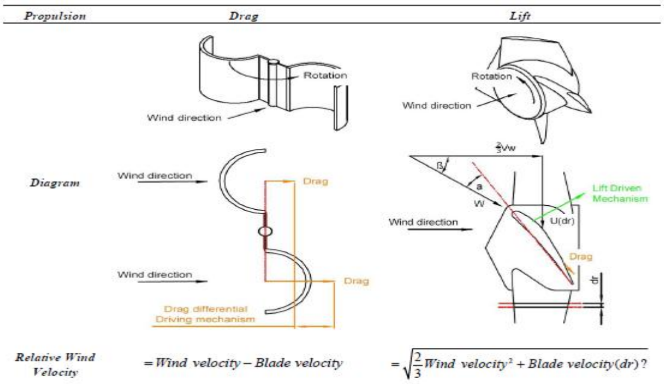

Table 1. The two mechanisms of propulsion compared.

3. CONCLUSIONS

For reasons of efficiency, control, noise and aesthetics the modern wind turbine market is dominated by the horizontally mounted three blade design, with the use of yaw and pitch, for its ability to survive and operate under varying wind conditions. The optimum efficient shape is complex consisting of aerofoil sections of increasing width, thickness and twist angle towards the hub. A uniformly distributed load can be used to represent aerodynamic lift during operation. Currently manufacturers are seeking greater cost effectiveness through increased turbine size rather than minor increases through improved blade efficiency. Minor changes to blade shape may then occur as manufacturers incorporate new aero foils, tip designs and structural materials. At the blade root, chord and thickness attain their maximum values. Twist is maintained in such a manner that the angle of attack gives the maximum lift coefficient. Chord distribution is same for both airfoils at all tip speed ratios. The power coefficient of a rotor varies with the tip speed ratio (the ratio of rotor tip speed to free wind speed) and is only a maximum for a unique tip speed ratio. The maximum power coefficient that can be achieved in the presence of drag is significantly less than the Betz limit at

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all tip speed ratios. Drag reduces the power coefficient at high tip speed ratios.

For a small wind turbine, the allowable size of the turbine creates constraints that reduce the number of parameters required to maximize the efficiency of the turbine. The main parameters constrained due to the size requirement are the length of the blade and the height of the center of the hub. While it was shown that the coefficient of power is not affected by either wind velocity or blade length alone, power output will increase with an increase in both parameters. The function also requires assumptions of the tip speed ratio and the most efficient angle of attack. The most efficient angle of attack was based on the angle of attack corresponding to the greatest ratio of coefficient of lift to coefficient of drag, which is a known value for any given airfoil.

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