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Factors affecting Performance OF Wind Turbine Blades

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ABSTRACT

In the wake of drastic depletion of conventional energy sources, there is a high demand for the non- conventional alternatives. Wind turbines provide an alternative way of generating energy from the power of wind. At windy places where the wind speeds are so high, sufficient amount of energy can be harnessed by making use of wind turbines. The blades of such turbines are so designed that they generate lift from wind and thus rotate. In the present study, wind turbine blade design is reviewed in detail, including aerodynamic efficiency and propulsive efficiency. The aerodynamic design principles for a modern wind turbine blade are detailed, including blade profile, aerofoil selection and tip speed ratio. Some of the existing wind turbine systems are presented with their usage in different industries and maximum efficiency.

Keywords: *Wind turbine, Blade design, Drag, Lift, Aerodynamics, Betz limit*

I. INTRODUCTION

The unpredictability and unreliability of wind both in terms me strength and heading demands careful designed and engineered wind turbines to produce useful amount of power. Generally wind turbine consist two or three blades rotating around horizontal axis and these propellers like blades convert the energy of the wind into usable shaft power by extracting the energy from the wind by slowing it down or decelerating the wind as it passes over the blades. These blades work on the concept of generating lift due to their curved surfaces same as the aircraft's wing. Blades should be designed in such a way that they produce sufficient amount of lift or thrust to get desirable power and to improve better blade efficiency.

The efficiency of energy extraction depends upon speed at which blade rotates if the rotation speed is too slow, a large amount of wind pass through them undisturbed and if the rotational speed is too high, blade disk appears s a large flat rotating disc, which creates a large amount of drag. Therefore, to improve wind turbine performance, tip speed ratio should be optimum and that depends on the rotor blade shape profile, the number of turbine blades, and the wind turbine propeller blade design itself. Hence, designing parameters such as number of blades, their speed, wind speed, blade profile greatly affects overall system performance.

Blade designer are constantly modifying the design parameter to achieve maximum power at minimum construction cost. These new modification provides more compact, quieter and efficient wind turbine system which generates more power from less wind. Blades are able to extract 5 to 10 percent more wind energy by slightly changing its curvature.

II. DESIGNING

The performance of blades is large affected by blade parameters such as blade profile, tip speed ratio, pressure efficiency, drag, lift.

Blade Profile

The Betz method provides the optimum chord length (Fig. 1) of the modern wind turbine blade, represented by the following expression. Where C_{opt} is Optimum chord length, U is Design wind speed (m/s), U_{wd} is wind speed (m/s), V_r is Local resultant air velocity (m/s), λ is Local tip speed ratio, C_L is Lift coefficient and n is Blade quantity.

$$C_{opt} = \frac{2\pi r}{n} \frac{8}{9C_L} \frac{U_{wd}}{\lambda V_r}$$

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$$V_r = \sqrt{V_w^{\,2} + U^2}$$

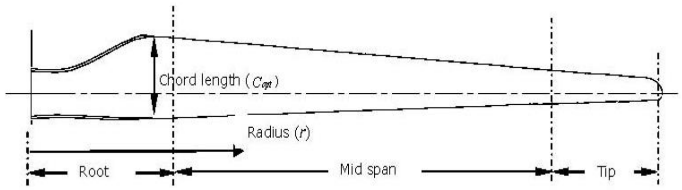

Figure 1. A typical blade planform

Airfoil selection

The structural requirements of turbine blades signify that aerofoils with a high thickness to chord ratio be used in the root region as thick aerofoil sections generally have a lower lift to drag ratio. Special consideration is therefore made for increasing the lift of thick aerofoil sections for use in wind turbine blade designs. Approaching the tip, blades blend into thinner sections with reduced load, higher linear velocity and increasingly critical aerodynamic performance. The differing aerofoil requirements relative to the blade region are apparent when considering airflow velocities and structural loads (Table 1).

Table 1. The aerofoil requirements for blade regions

Parameter	Blade Position (Figure 2)		
	Root	Mid Span	Tip
Thickness to chord ratio (%) ($(\frac{d}{c})$ Figure 2)	>27	27–21	21–15
Structural load bearing requirement	High	Med	Low
Geometrical compatibility	Med	Med	Med
Maximum lift insensitive to leading edge roughness			High
Design lift close to maximum lift off-design		Low	Med
Maximum CL and post stall behaviour		Low	High
Low Aerofoil Noise			High

Tip speed ratio

A higher tip speed results increased blade efficiency but it also has some adverse effects such as increased noise, aerodynamic and centrifugal stress. Tip speed 1-2 is considered as low speed and more than 10 is consider as high speed. Low tip speed results increased torque, decreased efficiency, less aerodynamic and centrifugal stress, whereas high tip speed results decreased torque, increased efficiency, more aerodynamic and centrifugal stress.

A blade rotating at higher speed would be producing more efficiency than a blade rotating a low speed. Hence, the same efficiency can be achieved by narrowing blade profiles and it also reduced material usage and lower production cost. Higher tip speed also associated with more centrifugal and aerodynamic forces that would increase the net loads acting on the blades and near to the region where blade connects. Thus difficulties arise to maintain structural integrity and preventing blade failure. As the tip speed increases the aerodynamics of the blade design become increasingly critical. Also, higher speed deals with the less torque results in a higher cut in speed and difficulty self-starting.

III. EXISTING DESIGN

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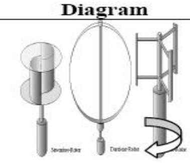
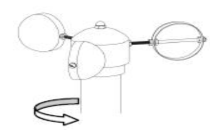
Over the vast period, many types of wind turbine design have developed with varying efficiency and usage. Some of the designs are listed in Table 2.

Table 2. Wind turbine designs.

Ref No.	Design	Orientation	Use	Propulsion	* Peak Efficiency	Diagram
1	Savonius rotor	VAWT	Historic Persian windmill to modern day ventilation	Drag	16%	
2	Cup	VAWT	Modern day cup anemometer	Drag	8%	
3	American farm windmill	HAWT	18th century to present day, farm use for Pumping water, grinding wheat, generating electricity	Lift	31%	
4	Dutch Windmill	HAWT	16th Century, used for grinding wheat.	Lift	27%	
5	Darrieus Rotor (egg beater)	VAWT	20th century, electricity generation	Lift	40%	
6	Modern Wind Turbine	HAWT	20th century, electricity generation	Lift	Blade Qty / efficiency: 1 – 43% 2 – 47% 3 – 50%	

IV. EFFICIENCY

To achieve high extraction of energy, blades efficiency should be optimum. Efficiency is measured in term of pressure energy at the expense of kinetic energy.

Propulsive efficiency

The strategy for propulsion basically influences the greatest reachable productivity of the rotor. Verifiably, the most usually used strategy was drag, by using a sail confronted ordinary to the breeze, depending on the drag factor (Cd) to create a power toward the overarching wind. This technique demonstrated wasteful as the power and turn of the sail compare to the wind heading; thusly, the overall speed of the wind is diminished as rotor speed builds as shown in Figure 2.

Drag	Lift

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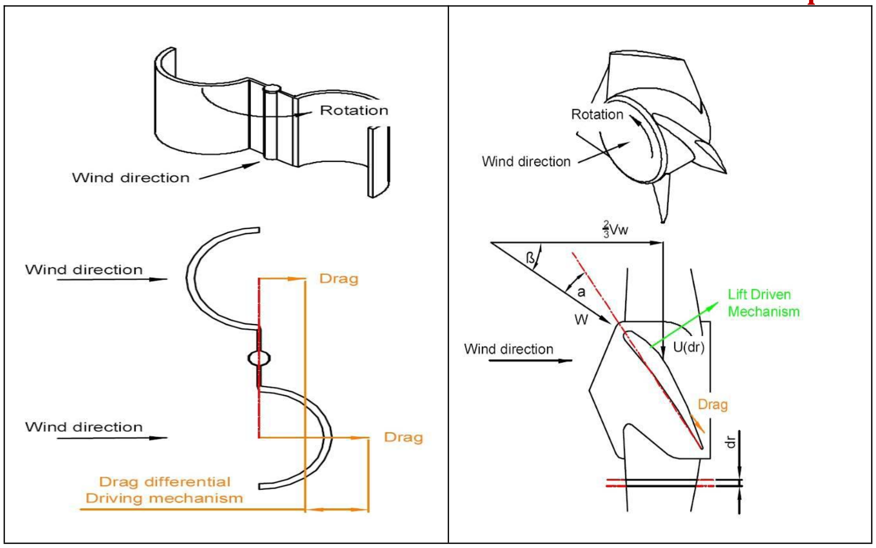

Figure 2. The two mechanisms of propulsion

Aerodynamic efficiency

100% extraction would imply zero final velocity therefore zero flow situations cannot be achieved hence all the kinetic energy cannot convert into pressure energy. A large number of research shows that wind turbine efficiency cannot exceed 59.3% otherwise flow would separate or it would be reversed. This limit on efficiency is refereed as Betz limit.

$$C_P = \frac{P}{0.5\rho u_\infty^{\ 3} A}$$

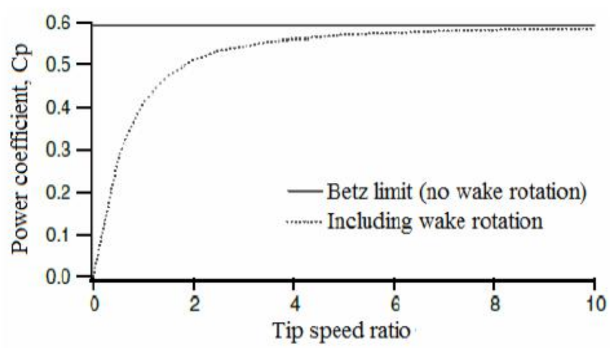

Figure 3. Theoretical maximum power coefficient as a function of tip speed ratio for an ideal HAWT with and without wake rotation

Where, C_p is coefficient of Power, u_R is velocity at rotor plane and P is the power which is the product of thrust and velocity at rotor and. The variation in coefficient of power with tip speed ratio is given by Betz limit.

V. CONCLUSION

An efficient blade shape is defined by aerodynamic calculations based on chosen parameters and the performance of the selected aerofoils. The optimum efficient shape is complex consisting of aerofoil sections of increasing width, thickness and twist angle towards the hub. This general shape is constrained by physical laws and is unlikely to change. However, aerofoil lift and drag performance will determine exact angles of twist and chord lengths for optimum aerodynamic performance. Currently manufacturers are seeking greater cost effectiveness through increased turbine size rather than minor increases through improved blade efficiency. This is likely to change as larger models become problematic through construction, transport and assembly issues. Therefore, it is likely that the general shape will remain fixed and will increase in size until a plateau is reached. Minor changes to blade shape may then occur as manufacturers incorporate new aerofoils, tip designs and structural materials. A conflict of increased aerodynamic performance in slender aerofoils versus structural performance of thicker aerofoils is also evident.

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