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The Effective Aerodynamic Forces on the Blade and the Rotor of the Wind Turbine

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Abstract

Betz theory presents the output power from the disk of wind turbine but the density of the power on the disk (the density of the forces along the blade) isn't cleared. Designing the profile of a wind turbine blade involves determining the aerodynamics and distribution of the lift forces along the blade. There is new method to calculate the relative velocity depending on knowing values ω Wake rotational speed and Ω Blade rotational speed [3], by this method the relative velocity will be known and the lift force will be known theoretically so knowing the efficient lift at particular parts of the blade will help engineers to develop design solutions for improving wind turbine output. This paper studies the distribution of relative velocity and the lift forces along the blade, this values will be calculated depended on several values of the tip speed ratio (TSR) for every situation.

Introduction

Renewable energy is one of power sources nowadays, but the challenges at these days economical unit for construction and uses. Wind energy is important power source, the cost to build a unit wind turbine is still high, that depended on the large size of blades wind turbine so that needs large sizes for other parts of the unit of wind turbine. Thus, engineers must fully investigate wind energy in order to design blades and rotors that can be manufactured, operated and maintained, preferably at least cost. Power generation from wind depends on the effects of aerodynamics forces on the blades of a turbine. Data collection and analysis of these forces make it possible to identify which part of a blade carries the main load, depending on this paper.

Literature review

Betz theory presents the max power can be extracted from the disk of wind turbine theoretically 59.26 percent [1]. Blade Element Momentum Theory (BEM) presents the solution for blade designing [2]. The Relationship between the Variables Values of Wind Turbines, Blade Rotational Speed, Wake Rotational Speed, Wind Velocity and Blade Tip Radius presented by my last research [3].

Figure (1) shows flow into the turbine blade, the relationship between velocity v(1-α), relative velocity W, and (rotation blade, rotation wake) [2].

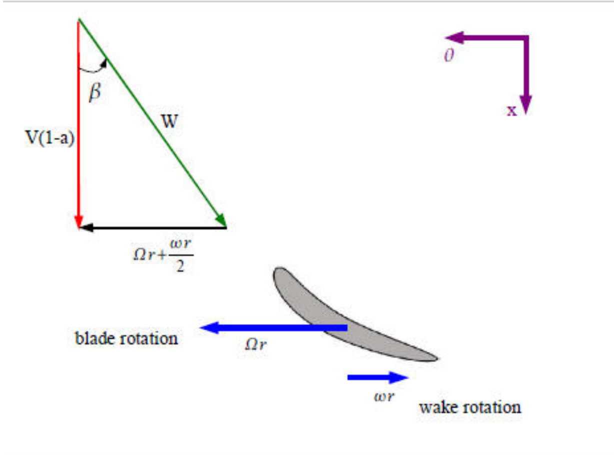

Figure (1) Flow into the turbine blade

Figure (2) shows the blade lift and drag forces on the turbine blade [2].

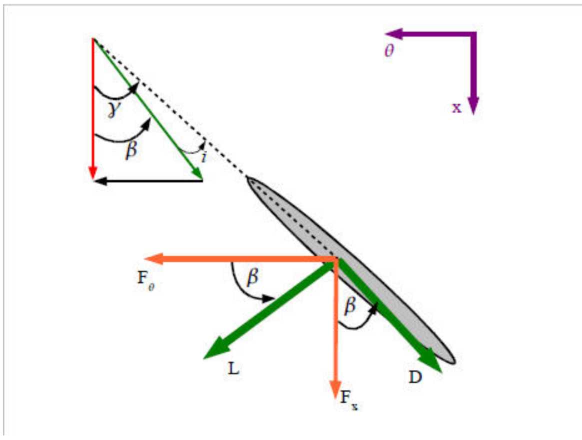

Figure (2) Forces on the turbine blade

The left and the drag forces can be obtained generally [2]:

$$dL = C_L \frac{1}{2} \rho W^2 c dr \quad (1)$$

$$dD = C_D \frac{1}{2} W^2 c dr \quad (2)$$

The relative velocity can be obtained:

$$W^2 = [v(1-a)]^2 + \left(\Omega r + \frac{\omega r}{2}\right)^2 \quad (3)$$

The above equations and figures give a simple idea about aerodynamics forces.
Figure (3) shows the left and drag coefficients that help to find the best value of C_L and C_D at a good degree of attack [2].

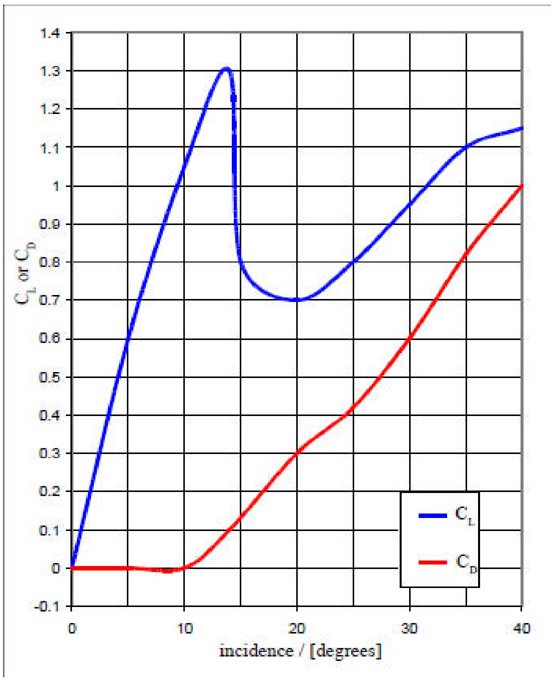

Figure (3) Lift and drag coefficients for an NACA 0012 airfoil

My research [3] presents equation about (Ω*ω, v, R).

$$\Omega \omega = \frac{8}{9} \frac{v^2}{R^2} \quad (4)$$

Effective forces

This study assumes the following:

- The theoretically assumptions are taken in this studying.
- Betz theory is used and the lift and drag forces are calculated simply.
- The indicated coefficient $\alpha = \frac{1}{3}$ at high efficient Betz theory and the attack degree = 7.5 – 9.5 so $C_D = 0$ $C_L=1$ are used.

Note: The above assumptions must be taken in this study because the study doesn't take any factor for real operation.

Rotational wake (ω) will be subjected in equation (3) so the relative velocity:

$$W^2 = \left[v\left(1-\frac{1}{3}\right)\right]^2 + \left(\Omega r + \frac{\frac{8v^2}{9R^2}\frac{1}{\Omega}r}{2}\right)^2 \quad (5)$$

$$W^2 = \frac{4}{9}v^2 + r^2\left(\Omega + \frac{4v^2}{9R^2}\frac{1}{\Omega}\right)^2 \quad (6)$$

$$w = \sqrt{\frac{4}{9}v^2 + r^2\left(\Omega + \frac{4v^2}{9R^2}\frac{1}{\Omega}\right)^2} \quad (7)$$

$$\Omega = \frac{\lambda v}{R} \quad (8)$$

$$w = \sqrt{\frac{4}{9}v^2 + r^2\left(\frac{v\lambda}{R} + \frac{4v}{9R}\frac{1}{\lambda}\right)^2} \quad (9)$$

$$w = v\sqrt{\frac{4}{9} + \left(\frac{r}{R}\right)^2\left(\lambda + \frac{4}{9}\frac{1}{\lambda}\right)^2} \quad (10)$$

Equation (10) shows the relationship between the relative velocity *w* , v wind velocity, and tip speed ratio λ. This equation will be discussed to find the high value of relative velocity and then the high lift force will be cleared from equation (1).

Figure (4) shows the value of relative velocity W on every point along the blade when the tip speed ratio (TSR)λ=1 and the wind velocity has several values, 3 m/sec, 7 m/sec, 10 m/sec, 13 m/sec, 20 m/sec, when λ=1 which is the minimum value. . Figure (4) shows that the relative velocity W changes very little along the blade at wind velocity 3 m/sec, meaning that the difference changes of relative velocity W increase as the wind velocity increases. Figure (4) also shows little difference in the value of relative velocity at TSR=1 and low wind velocity, meaning that there will be minimum value along the blade but a high value at the end part of the blade will be at high velocity.

All of the above results will be shown the main load or the stresses will occur at the end part or the tip part of the blade.

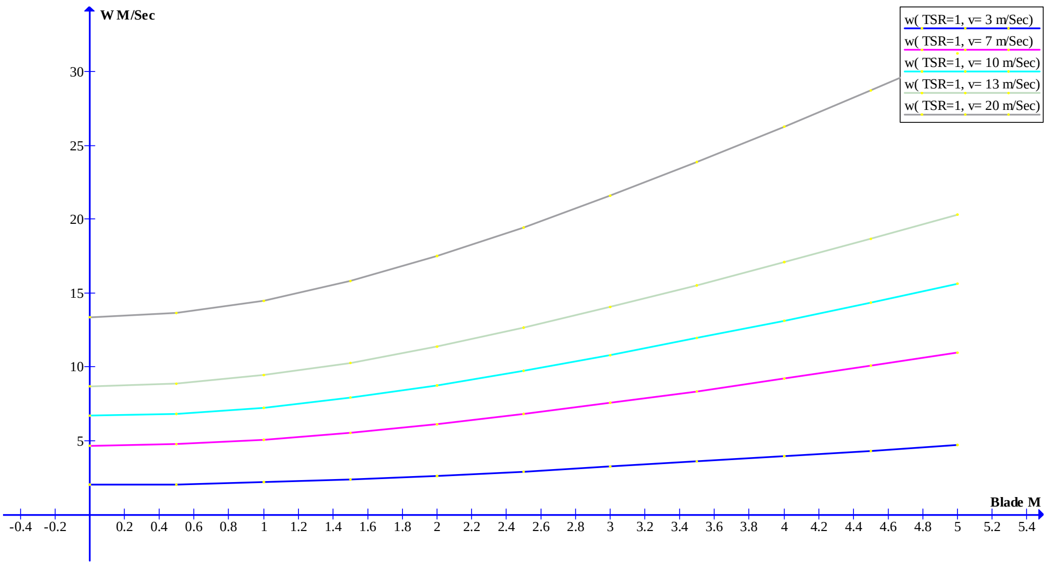

Figure (4) The distribution relative velocity W along the blade at deference wind velocity (3,7,10,13,20 m/sec) when λ=1

Figure (5) shows the value of relative velocity W on every point along the blade when wind velocity 7 m/sec and λ has several value λ=(1,2,4,6,8,10,15). Since the value of relative velocity W increases when λ increases, it is clear that the highest value will be at the last point of the blade.

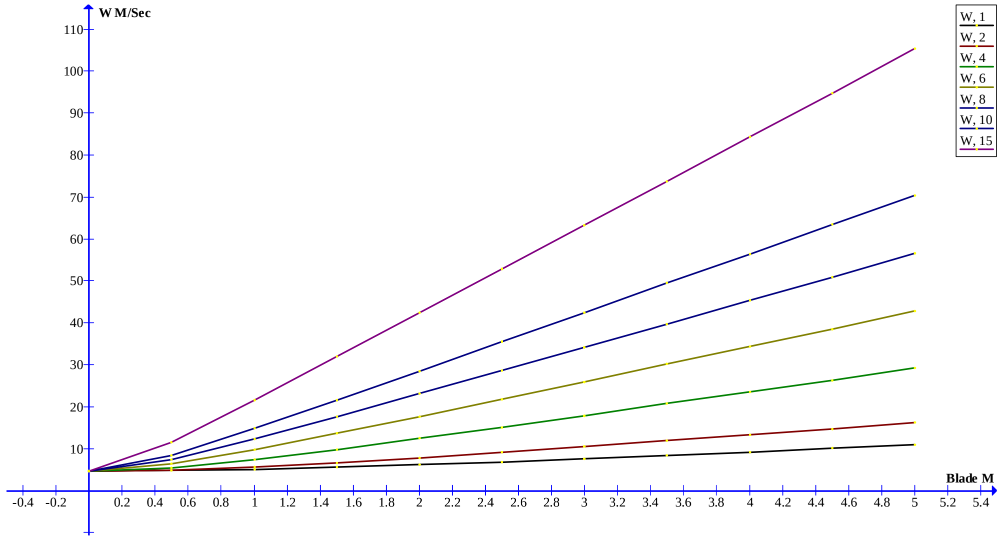

Figure (5) The distribution relative velocity W along the blade at deference λ=(1,2,4,6,8,10,15) when air velocity=(7m/sec)

The results in figure (6) show there are high differences when (TSR) λ equal 1 and 15, so when λ=1, the value of lift forces does not change very high along the blade. In other words, when (TSR) λ increases, the differences will increase between the beginning blade (at the center rotor of the wind turbine) and at the end blade (the tip part of the blade), there is important note about the value at the end of radiuses, it must be zero when the turbine rotate real operation but now it's theoretically studying.

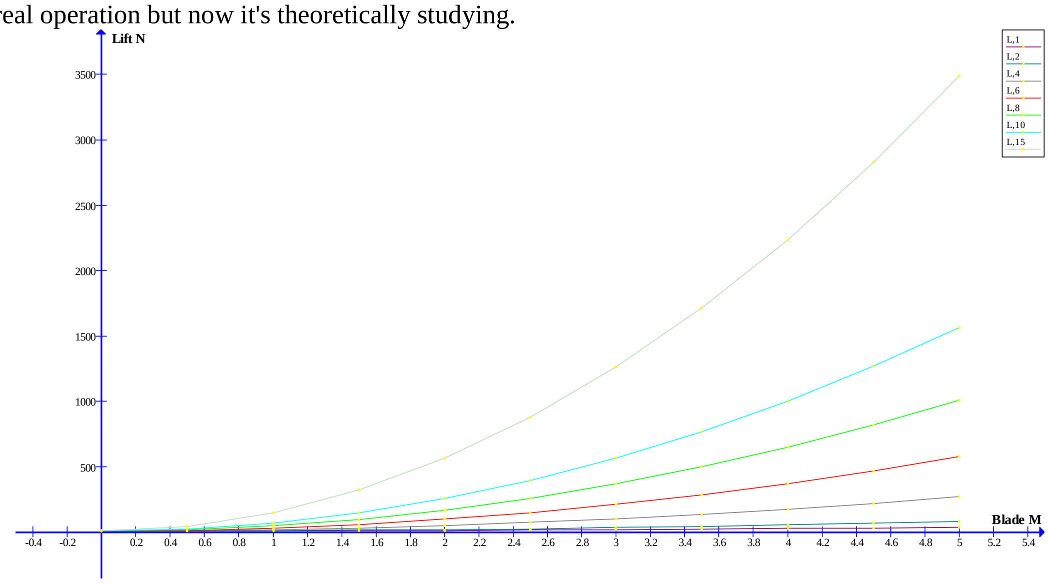

Figure (6) The distribution lift forces L along the blade at deference λ=(1,2,4,6,8,10,15) when air velocity=(7m/sec)

Density the power on the disk:

There are two way to know the density the power on the rotor wind turbine in this paper Betz theory:

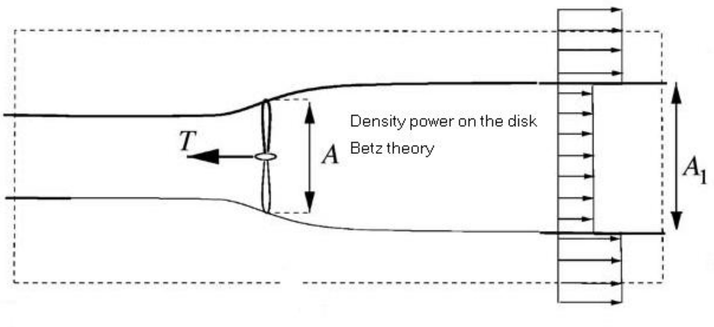

Figure (7) Density power on the disk Betz theory

Density power depended on relative velocity:

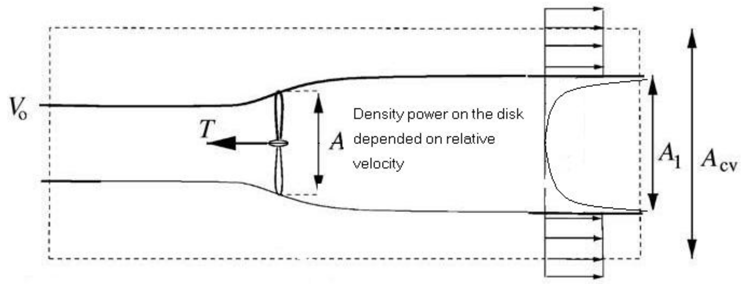

Figure (8) Density power on the disk depended on the relative velocity

These situations are shown the differences of density power on the rotor depended on Betz theory and the density power depended on the relative velocity so the main area which loaded the main forces is cleared.

Conclusion

The above study has shown the distribution of relative velocity W and lift forces L on the blades of a wind turbine. The research has focused on the main lift forces along the blade of a wind turbine because the stress along the blade and the efficient lift forces will be known at the particular part of the blade at every situation of wind velocity. The results show that the wind turbine at high λ will take a small size turbine and blades and a high-speed rotor instead of a typical larger turbine.

Figure (6) has shown the distribution lift forces along the blade. When λ=1, the lift forces along the blade have a low value and the same distribution along the blade means a wider profile blade c and more blades. In addition, this situation can be taken from λ=1,2,3,4 so λ=5,6,7,8, the blades will be decreased and the section of profile will be decreased finally λ=9,10,11,12,… the value of lift forces does change very high along the blade so the designer has choices to find out the critical part of the blade which has major load so the profile of the wing will have different shapes from point to another point along the blade. In the other hand the density power on the rotor will be known so more and more the main area on the rotor will be known which hold the main load.

Finally, the blade of wind turbine will take new shape depended on this paper so the wind turbine sizes will be smaller but more research is needed.

Key words

Air speed, Blade rotational speed, Wake rotational speed, Lift force, Drag force, Relative velocity.

List of figures

Nomenclature

α Axial induction factor
A Area
c Aerofoil chord length
C_D Coefficient Drag Force
C_L Coefficient Lift Force
D Drag force
F Force

r Radiuses and radial direction
R Blade tip radius
v Wind velocity
λ Tip speed ratio
Ω Blade rotational speed
ω Wake rotational speed
γ Airfoil inlet angle

REFRENCES

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