RESEARCH ARTICLE OPEN ACCESS

"Design and Analysis of a Windmill Blade in Windmill Electric Generation System"

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ABSTRACT
Wind turbine is a standout amongst the most imperative wellsprings of renewable vitality. Wind turbine extricate active vitality from the wind. A little wind turbine cutting edge was composed and examined in this work. The power execution of little flat hub wind turbines was mimicked in detail utilizing altered blade element momentum methods (BEM). Another sharp edge was planned utilizing diverse assault points (i.e.0^o, 5^o, 10^o), distinctive speed (4m/s, 5m/s and 12m/s) and rotor span (0.5m and 1m). From this we discover harmony length and power yield hypothetically. Likewise, we chose material for proposed sharp edge.
Keywords: Drag co-efficient, Lift coefficient, Wind turbine power coefficient, Maximum wind turbine power coefficient, Wind turbine power output

I. INTRODUCTION

As of late, wind vitality has attracted more consideration because of the expanding costs of fossil fills and enhancing financial intensity of wind turbines in respect to ordinary era advancements. Today, wind vitality has been produced into a develop, focused, and for all intents and purposes contamination free innovation. Normally a regular substantial, utility scale wind turbine can create 1.5 to 4.0 million kWh yearly and works 70-85% of the time. Worldwide wind vitality generation set another record in 2011, achieving 239 GW, 3% of aggregate power creation. It is anticipated that by 2020 it will increment to 10% of worldwide power creation.[1,2]The American Wind Energy Association revealed in 2010 that creation of little flat hub wind turbines would increment quickly later on because of gigantic request. For the order of level hub twist turbines, there is no settled standard. The National Renewable Energy Laboratory in US characterizes wind turbines whose appraised power are not more noteworthy than 100 kW, and whose width are close to 19 m as little wind turbines. Clausen and Wood (2000) characterized a little twist turbine as having a most extreme power yield of 50 kW, and further isolated little twist turbines into three classifications: miniaturized scale turbines (most extreme 1 kW); mid-run (bigger than miniaturized scale ones and littler than small scale ones), typically 1 kW to 5 kW; and smaller than usual turbines whose power more prominent than 20 kW. [3]The innovation of huge wind turbines has been created well, be that as it may, little wind turbines require more research in view of various structures and distinctive applications from substantial ones.In spite of the fact that Computational Fluid Dynamics (CFD) has been creating to investigate optimal design of wind turbines, the Blade Element Momentum (BEM) strategy is still connected generally for it is a straightforward, prompt and successful technique for little wind turbine plan and execution examination. [5] The essential idea of BEM is to partition the wind turbine edge into areas traverse shrewd, as appeared in Figure 1 (Burton, 2001), then compute the strengths on every component with the supposition that all components are autonomous from each other. At last, the aggregate powers and minutes on the sharp edge can be dictated by the coordination of partitioned strengths and minutes on each segment [11]

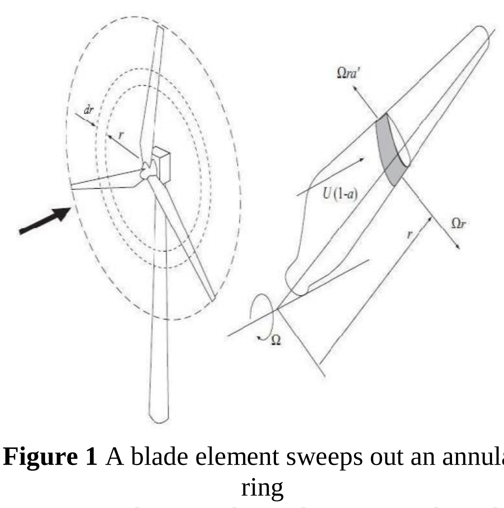

Figure 1 A blade element sweeps out an annular ring

Another vital angle in wind turbine research is sharp edge materials. The transfer of utilized wind turbines cutting edges is a hazardous issue that scientists everywhere throughout the world are confronting. Current techniques for wind turbine edge transfer incorporate landfill, burning and restricted reusing.[3] In any case, clearly no transfer technique is great. An option that can moderate a portion of the issues with current transfer strategies is to create "green" materials to supplant the customary materials. The venture Hierarchical Green Nano-Bio composites for Light Weight and Efficient Wind Turbines Blades was propelled to investigate new sharp edge materials from bio-hotspots for little twist turbines with enhanced power execution.[5]

II. OBJECTIVES

The objective of this project was to design a new blade for a small wind turbine and predict wind turbine power output at different wind speeds, different attack angles and different rotor diameter.

III. BLADE ELEMENT MOMNTUM THEORY

The BEM was also from blade element theory, and was developed with these assumptions: each element is independent of the others, with no radial interaction, and almost constant axial flow induction factor.

Airfoil

The airfoil is the most critical and major component in building a wind turbine sharp edge. Airfoil qualities will decide the execution of the wind turbine, communicated regarding C_T and C_P.

Lift coefficient and drag coefficient of airfoil are the integral for outlining a wind turbine and the premier parameters to be considered. These coefficients rely on upon Reynolds number. In liquid elements, non-dimensional Reynolds number is characterized as

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

where 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.

Lift coefficient and drag coefficient could be measured in two-dimension or three-dimension. In rotor design, two-dimensional coefficients are adopted widely. They are defined as followed.[11]

$$C_l = \frac{L/l}{\frac{1}{2}\rho U^2 c} \ and \ C_d = \frac{D/l}{\frac{1}{2}\rho U^2 c}$$

Where C_l is lift coefficient, C_d is drag coefficient, *l* is the airfoil span.

The lift coefficient and drag coefficient of an airfoil are a function of the angle of attack and Reynolds number. Airfoil behavior in the air flow is divided into three phases: the attached flow phase, the high lift/stall development phase and the flat plate/fully stalled phase. In small wind turbine design, designers prefer high lift coefficient and relatively low drag coefficient at low angle of attack, and try to operate with the airfoil in the attached flow phase if possible, though some stall-regulated wind turbines operate in high lift/stall development phase.[11]

Blade Element Analysis

As shown in figure, the following relationships among the parameters can be determined as below[11]

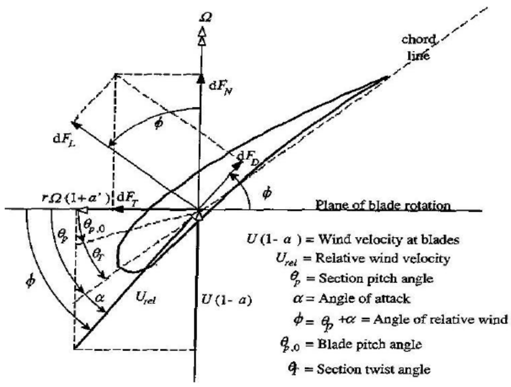

Figure 2 Blade geometry for analysis of wind turbine

$$\theta_T = \theta_p - \theta_{p,0}$$
$$\emptyset = \theta_p + \alpha$$
$$\tan \emptyset = \frac{U(1-\alpha)}{\Omega r(1+\alpha')} = \frac{1-\alpha}{(1+\alpha')\lambda_r}$$
$$U_{rel} = \frac{U(1-\alpha)}{\sin \emptyset}$$

In Figure, θp is area pitch point, θp is cutting edge pitch edge at the tip, θ_T is segment curve edge which is characterized in respect to the tip, α is the approach, Ø is the edge of relative wind, dF_l is the incremental lift constrain, dF_d is the incremental drag compel, dF_N is the incremental drive typical to the plane of revolution (identified with push), and dF_T is the incremental constrain digressive to the circle. cleared by the rotor, which adds to the helpful torque, U_{rel} is the relative wind speed, U (1-an) is twist speed at edges.Generally normal load coefficient C_n and tangential load coefficient C_t are defined as[11]

$$C_n = C_l \cos\emptyset + C_d \sin\emptyset$$
$$C_t = C_l \sin\emptyset + C_d \cos\emptyset$$

And σ is the local solidity, defined by:

$$\sigma = \frac{Bc}{2\pi r}$$

Where, *c* is chord length of blade at radius *r*.

dFN=dT and dQ=dQ, two equations can be obtained as below:

$$\alpha = \frac{1}{1+\frac{4\sin^2\phi}{\sigma c_l}}$$

$$\alpha' = \frac{1-3\alpha}{4\alpha-1}$$

IV. POWER CALCULATIONS

Design calculation can be followed by step by step procedure as described below:

$\lambda_r$is a tip speed ratio used to find$\emptyset_i$, from $\emptyset_i$, we find chord length and axial induction factor and radial induction factor as described in Betz's theory.We also find coefficient of power and coefficient of thrust. At last we find theoretical power from equation:[11]

$$P = \frac{1}{2}\rho\pi R^2 U^3 C_p \eta_m \eta_g$$

$$\lambda_r = \frac{r\Omega}{U}$$

Where, r is blade radius, Ω is angular velocity, U is stream velocity and is tip ratio

$$\lambda_{optimum} = \frac{2pi}{3}\left(\frac{r}{s}\right)$$

Where, n is number of blades, r local blade ratio, s is length of downwind and upwind.

$$s = \frac{r}{2}$$

$$\lambda_{optimum} = 4.18$$

$$(\lambda_r)_i = \lambda\frac{r_i}{R}$$

$r_i = 0.8R$ and $(\lambda_r)_i = 3.352$

$$\emptyset = \frac{2}{3}\tan^{-1}\left(\frac{1}{(\lambda_r)_i}\right)$$

$$C_i = \frac{8\pi r_i}{3C_L}(1-\cos\phi)$$

$c_p = 4\alpha(1-\alpha)^2$ and$c_T = 4\alpha(1-\alpha)$

R (m)	U (m/s)	$P = \frac{1}{2}\rho\pi R^2 U^3 C_p \eta_m \eta$ (Watts)
0.5	3	6.238
0.5	4	14.75
0.5	5	28.85
1.0	3	24.93
1.0	4	69.10
1.0	5	115.43
1.5	3	56.10
1.5	4	132.98
1.5	5	260

Table 1 Calculation of power from input speed and radius

V. DESIGN OF BLADE

The blades are perhaps the most important part of our wind turbine. These wind turbine blade have airfoil shape. The blade materials are carbon fiber and aluminum alloy.

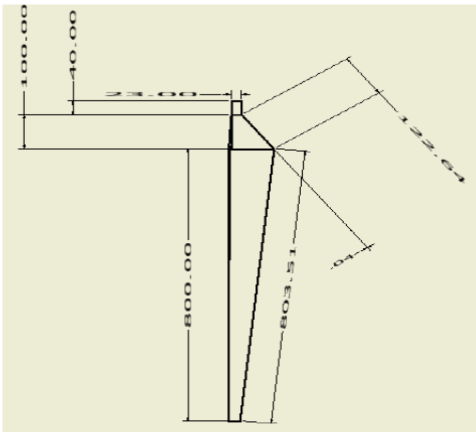

Figure 3 The front view of blade with dimension

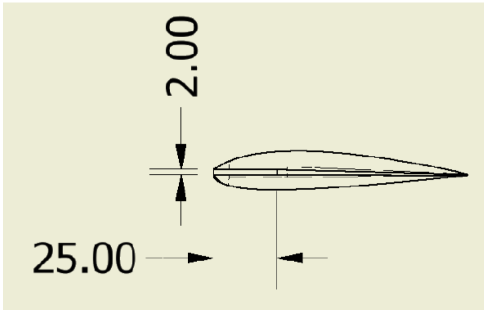

Figure 4 Side view of blade

Details of NACA 2415 airfoil

The NACA airfoils are airfoil shapes for flying machine wings created by the National Advisory Committee for Aeronautics (NACA). The state of the NACA airfoil is depicted utilizing a progression of digits taking after "NACA". The edge NACA 2415 mean: Maximum camber 2% at 40%(0.4) harmony from driving edge with a most extreme thickness 15% at 30% (0.3) harmonies from the main edge.

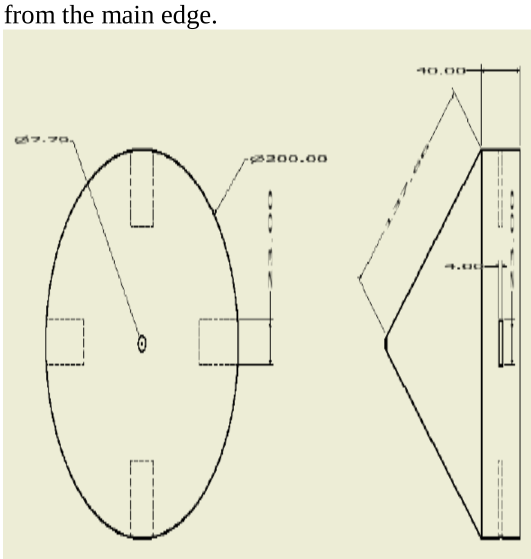

Figure 5 Rotor Details

Material Properties

- Aluminum alloy

Properties:
Density = 2700 Kg/m^3
ultimate tensile strength = 3.1 X 10^8 Pa
Young's modulus of elasticity = 7.1 X 10^{10} Pa
Tensile yield strength = 2.8 X 10^8 Pa
Compressive yield strength = 2.8 X 10^8 Pa
Coefficient of thermal expansion =2.3 X 10^{-5} K^{-1}
Poisson ratio = 0.33

- Carbon fiber

Properties:
Density = 1600 Kg/m^3
ultimate tensile strength = 4.15 X 10^9 Pa Young's modulus of elasticity = 2.310 X 10^{11} Pa
Tensile yield strength = 2.3 X 10^8 Pa Compressive yield strength = 6.1 X 10^8 Pa

Length m	Velocity m/s	Angle of Attack	Pressure (Pa)
0.4	4	0°	11.30
		5°	11.43
		10°	11.42
	5	0°	17.26
		5°	17.37
		10°	17.36
	12	0°	94.75
		5°	94.70
		10°	96.08
0.9	4	0°	11.98
		5°	11.94
		10°	12.09
	5	0°	18.14
		5°	18.15
		10°	18.40
	12	0°	98.03
		5°	98.26
		10°	101.70

Table 2 pressure at different length of blade, velocity and angle of attack

VI. APPLICATION

- **To light a 60 Watt bulb**

Then energy required:
In that case 1 second is 1/3600 of an hour, 60W is 0.060 kW
So, the energy consumed to light a 60W bulb for 1 second is 0.060 x 1/3600 = 0.00001666kWh

If wind velocity is 4m/s, then power output will be 0.00109576 kWh
Total number of bulbs can be light simultaneously =0.00109576/0.00001666 = 65 bulbs

If wind velocity is 5m/s, then power output will be 0.003522 kWh
Total number of bulbs can be light simultaneously = 0.003522 /0.00001666 =211

- **Fan**

Bajaj Bahar Deco 1200mm fan consumes 73Watt
In that case 1 second is 1/3600 of an hour, 60W is 0.0730 kW
So, the energy consumed to light a 73W fan for 1 second is 0.073 x 1/3600 = 0.0000202778 kWh
If wind velocity is 4m/s, then power output will be 0.00109576 kWh
Total number of fans can be rotated simultaneously = 0.0730 /0.0000202778 = 53
If wind velocity is 5m/s, then power output will be 0.003522 kWh
Total number of fans can be rotated simultaneously= 0.003522 /0.0000202778 = 173

VII. CONCLUSION

The followings are the points concluded from the project work:

- For the same design mass of aluminum alloy is higher than the carbon fiber and there is a huge difference in costing for both materials i.e., carbon fiber is more economical.
- 0.9m blade is more suitable compared to 0.4m blade for required power output as higher pressure is achieved on it.
- Maximum pressure occurs when attack of angle is 7° (after analyzing 0°, 5° and 10° we observe that pressure increase from 0° to 7° and afterward it decreases from 7°to 10°. The maximum pressure occurs at 7° angle).
- The cl/cd ratio is almost same at 7° attack angle and 10° attack angle but pressure difference is higher.
- From this project work we conclude blade parameters as: Blade length= 900mm Blade material: Carbon fiber Angle of attack: 7°

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