"Design & Analysis of Small Wind Turbine Blade at Low Wind Speed region"

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ABSTRACT

A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy, this energy is known as wind power. The main focus is on the relationship between tip speed ratios, wind velocity maximum power coefficient. In this study, airfoil SG 6043 was selected and studies were conducted for variable chord and twisted blade, with blade numbers 3, 5 and 7. The main objective was to minimize the cut-in wind speed and to maximize the annual energy production from such a machine. A simulation based design and optimization process was adopted and in this thesis these parameters are calculated by using Mat lab program

***Keywords**: Wind Energy, Renewable Energy, Windmills, Small Wind Turbines, Environment, BEM Theory, X-Foil, Chord, Twist, Airfoil.*

1. INTRODUCTION

Wind power, as an alternative to fossil fuels, is abundant, renewable, and extensively circulated, clean, produces no greenhouse gas emissions during operation and uses little land (Fthenakis, et al., 2002). If the efficiency of a wind turbine is increased, then more power can be generated thus decreasing the need for expensive power generation that causes pollution. Ever since the seventh century, people have been utilizing wind to make their lives easier (***Satish et al.,*** 2011). Renewable energy sources are those energy sources, which are not spoiled when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as biological hydrogen production and geothermal heat. Amongst the above mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind (Patnaik et al., 2009). The energy transferred to rotor by the wind depends on the air density, the swept area of the rotor and wind speed. Blade is the key component to capture wind energy. It plays a vital role in the whole wind turbine. Turbine power production depends on the interaction between the rotor and the wind (Man well, 2002),

1.1 Wind Turbine Blade

A wind turbine uses the aerodynamic force of the lift to rotate a shaft which in turn helps in the conversion of mechanical power to electricity by means of a generator. For this purpose there are mainly two types of wind turbine and these are given bellow-

i) Horizontal axis wind turbine ii) Vertical axis wind turbine

2. REVIEW OF WORK CARRIED OUT ON DIFFERENT INDIVIDUAL PARAMETER:-

A] Small wind turbine at low wind speed

Small wind turbines operating at low wind speeds regularly face the problem of poor performance due to the laminar separation and laminar separation bubbles on the blades. This is due to the low Reynolds number resulting from low wind speeds and small rotor size.

Singh and Ahmed (2013), has discussed about, a 2-bladed, 1.26 m diameter rotor was designed for low wind speed conditions. The rotor was designed for the Air-X marine wind turbine which has a similar rotor diameter of 1.16 m. The 2- bladed rotor was manufactured from wood to achieve a low rotational inertia for easy start up in low wind conditions and fiber-coated for stiffness and strength. Taper and twist distributions were incorporated in the design of the rotor. A low Reynolds number airfoil designated as AF300 was specially designed for the rotor blades.

B] Rotor Blade

Wright and Wood (2004) stated that, it is vital that small wind turbine rotors have a good startup response to low wind speeds in order to generate maximum possible power Most of the starting torque comes from near the blade root whereas the tip generates most of the power producing torque The starting torque of small wind turbines is small due to their small rotor size deeming it insufficient to start at low wind speeds. Small wind turbines suffer from a lot of resistive torque generated by friction linked to gearbox train, bearings and generator, all of which the rotor has to overcome before it can start rotating. As wind turbines get smaller, cogging friction

3. METHODOLOGY AND DESIGN PROCEDURE

In which before cut-wind speed and after cut-out speed power develops is zero while rated speed to cut out speed power remains constant, where as in power curve without control device, the power decreases as the controller device has been not used. But as compared to theoretical power curve, in case of actual power curve, cut-wind speed to rated wind speed, electrical power increases. Electrical power expression can be expressed as, when wind velocity in between cut wind speed to rated wind speed. Then electrical power expression can be written as,

$$P = \frac{1}{2}\rho A V^3 C_p \eta_g \quad V_{cut-in} < V < V_{rated} \qquad P = P_{rated} \quad V_{rated} < V < V_{cut-out}$$

$$P = 0 \qquad V < V_{cut-in} or V > V_{cut-out}$$

Where, P= Electrical power in watts or kilowatt ρ = Air density (kg/m3) A= Swept area of the turbine blades (m^2) V= Wind speed (m/s) η_g =Generator efficiency.

4. ANALTICAL DESIGN RESULT DISSCUSSION

4.1 Power velocity curve for different number of blades

Figure no 1 indicated that when wind velocity increase that means power increases for number of blade= 3, 5 and 7 respectively the maximum rated power obtained 388 W, 422 W and 405 W at the rated wind velocity = 8 m/s. respectively this is called as rated power and rated wind speed respectively. velocity and generator efficiency is taken 0.2 to 0.92.

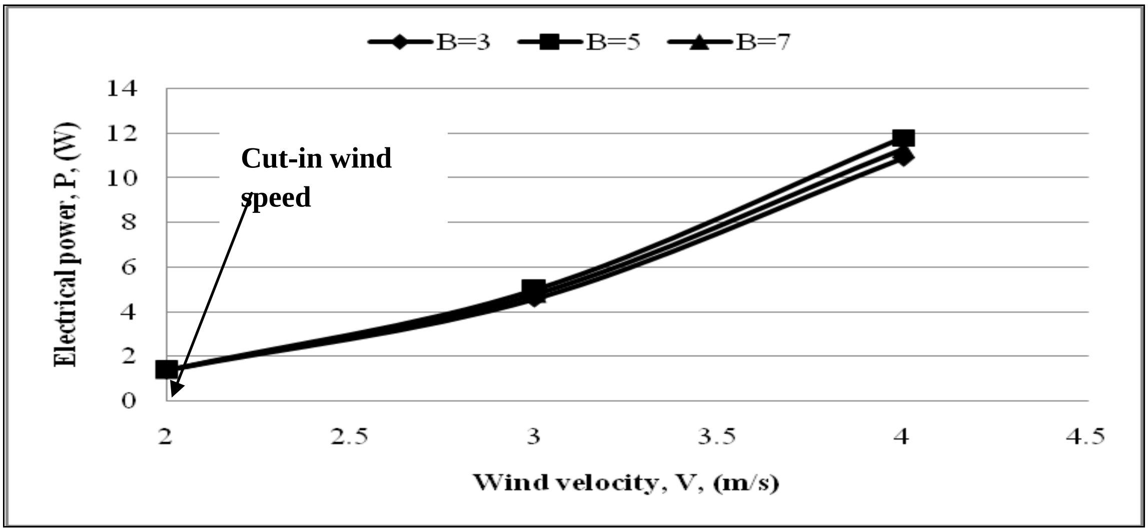

Figure 1 Power versus wind speed (2-4 m/s) for different number of blade

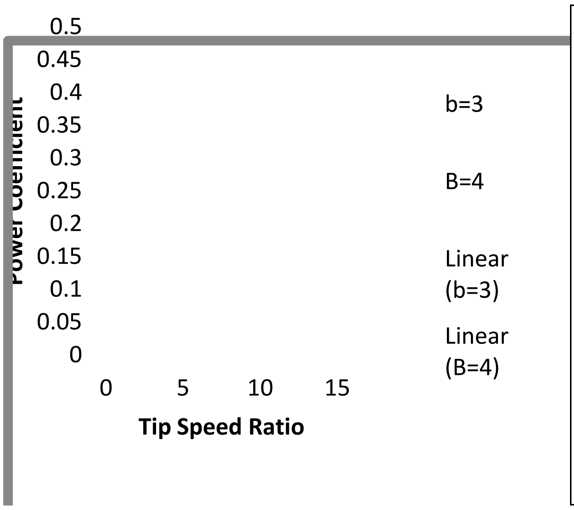

Figure 2 Power Coefficient Vs Tip Speed Ratio

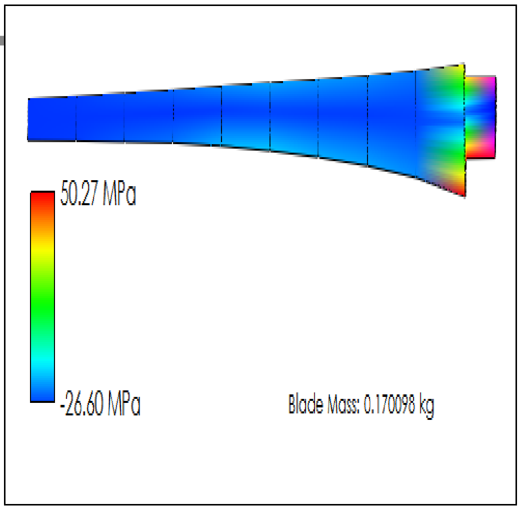

Figure 3 Structural Analysis

5. STRUCTURAL BLADE DESIGN AND ANALYSIS

Structural analysis of blade design is done in the Q- Blade software. For the analysis first Turbine BEM simulation is done and cut in wind speed and rated wind speed values are entered and simulation is done. This simulation is further used in structural blade design and simulation. Values of modulus of elasticity and density for selected material are entered and analysis is done. Here value of modulus of elasticity and density for ABS is entered. Value of Modulus of elasticity (E) = 2.6 * 10^9 Mpa and density ρ = 1052 kg/m3 Also static loading of blade and deflection can be found out from this simulation. Figure 3 above shows structural analysis of blade also mass of the blade is shown in figure no 3.

Table 1 indicates that chord and twist distribution and figure 4 indicates that blade geometry for number of blade =7

Table: - 1 chord and twist distribution for blade number=7 and tip speed ratio=6

Sr. No.	**Elemental section radius, r/R (m)**	**Chord, *c* (m)**	**Twist angle,(θ)**
1	0.968	0.001	7.74
2	0.905	0.001	8.39
3	0.841	0.001	9.11
4	0.778	0.006	9.75
5	0.715	0.02	10.02
6	0.651	0.03	10.35
7	0.588	0.05	10.74
8	0.525	0.06	11.18
9	0.461	0.08	11.94
10	0.398	0.11	13.01
11	0.335	0.14	14.54
12	0.271	0.18	16.87
13	0.208	0.22	20.63
14	0.145	0.25	27.58
15	0.081	0.05	61.81

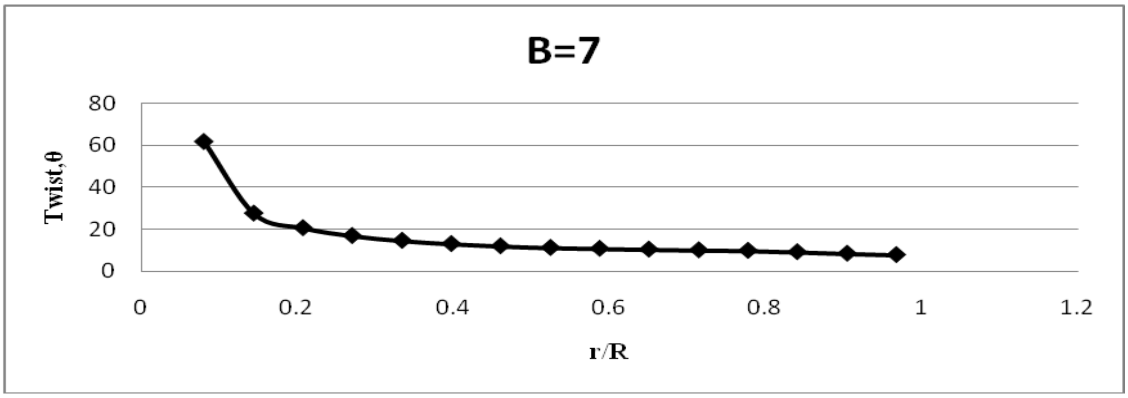

Figure 4 Twist distributions for SG 6043 airfoil

6 MODELING & MANUFACTURING

After the selection of airfoil the next step is modeling of blade in any of the design software. We have used Solid works software for the same. Initial step in constructing a model of blade in Solid works starts with importing the airfoil of desired chord length for each of the section. We have divided the blade in ten sections with 80 mm distance between each section. Airfoil was imported from air tools website and plotted on each plane using convert entities command of Solid works, then by using the lofted command model was constructed in Solid works. Figure no 5 & 6 blade model in solid works and prototype model made by thermocouples.

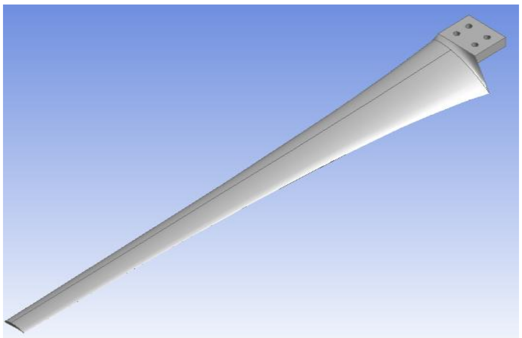

Figure 5 Models in Solid works

Figure 6 Prototype Model

6.1 Prototype Modal:-

Manufacturing by 3D printing process using ABS is amorphous and therefore has no true melting point. ABS is a terpolymers made by polymerizing styrene and Acrylonitrile in the presence of polybutadiene. The most important mechanical properties of ABS are impact resistance and toughness. A variety of modifications can be made to improve impact resistance, toughness, and heat resistance. The impact resistance can be amplified by increasing the proportions of polybutadiene in relation to styrene and also Acrylonitrile, although this causes changes in other properties. Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads. Thus, by changing the proportions of its components, ABS can be prepared in different grades. Characteristics within a temperature range from −20 to 80 °C (−4 to 176 °F).

7. RESULTS & DISCUSSION

Figure no 7 represents optimized blade models in Q- Blade software by using SG 6043 airfoil.

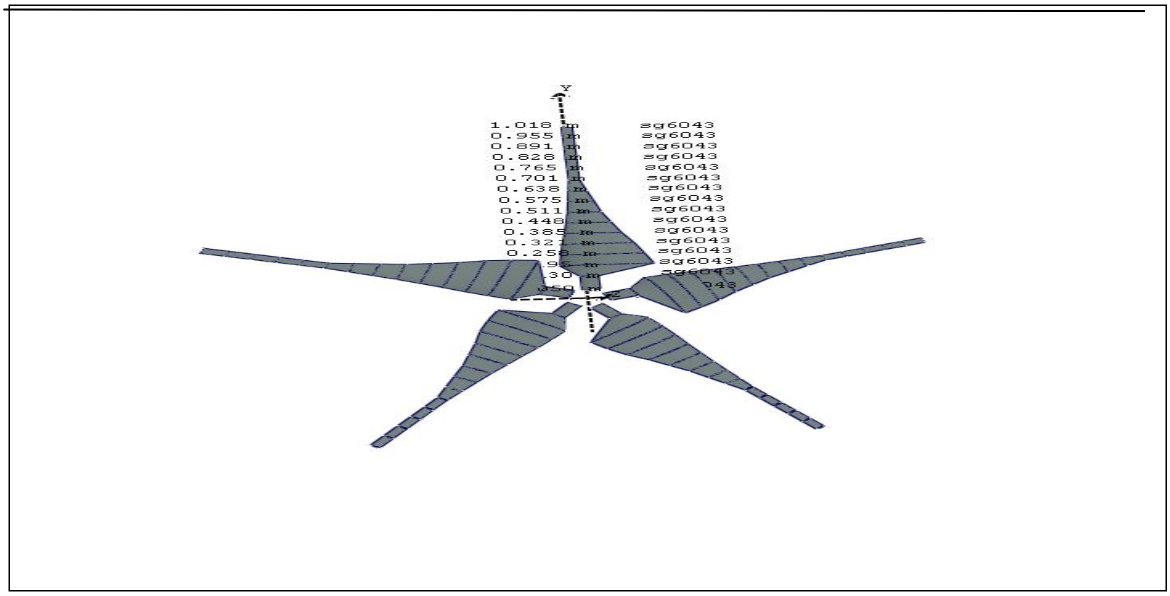

Figure 7 Q-5Bladed at optimized Pitch angle.

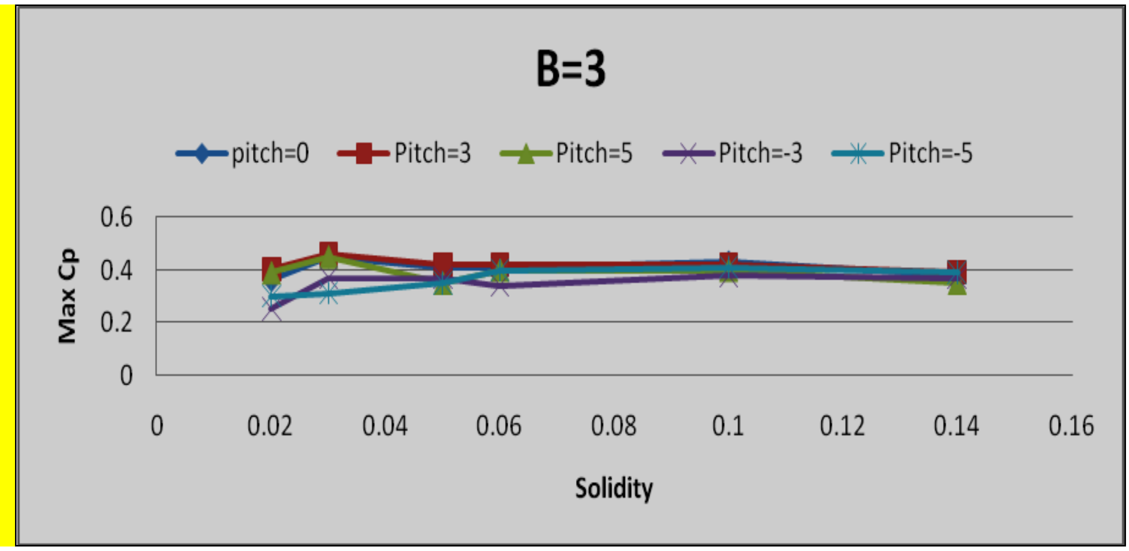

Figure 8 Max Power Coeff. Vs Solidity at various pitch angle for no. of blade=3

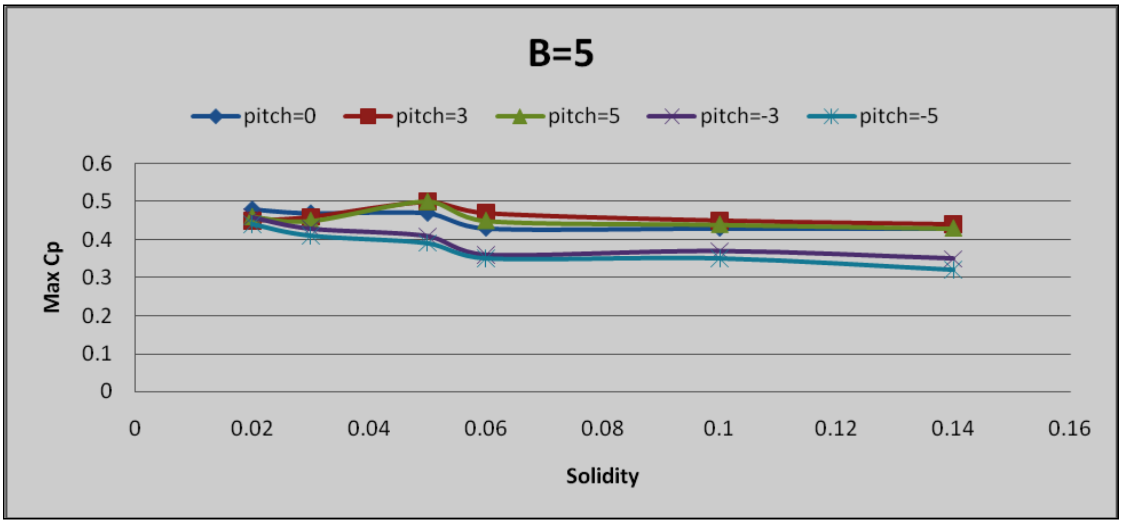

Figure 9 Max Power Coeff. Vs Solidity at various pitch angle for no. of blade=5

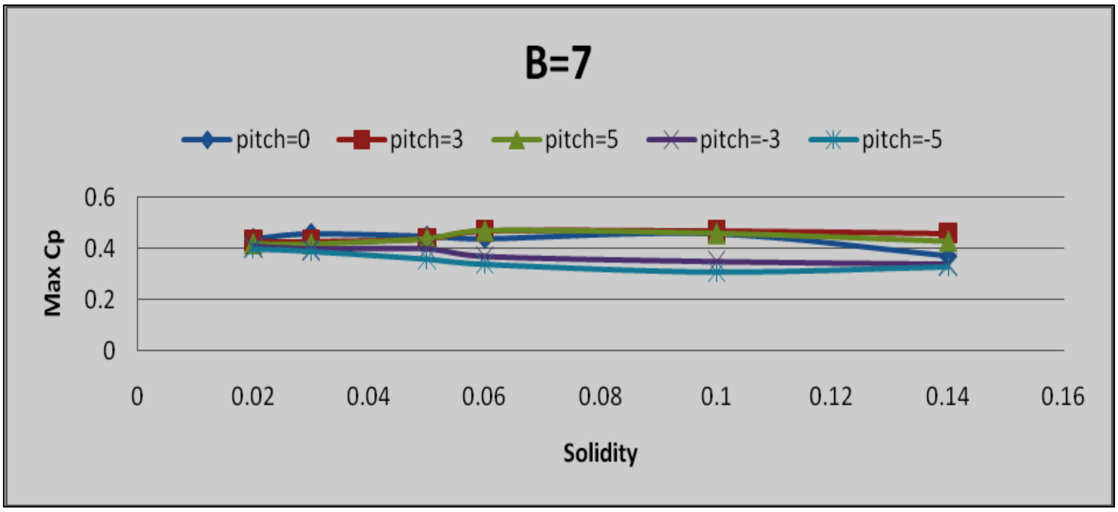

Figure 10 Max Power Coeff. Vs Solidity at various pitch angle for no. of blade=7

This paper provides a complete picture of wind turbine blade design and shows the dominance of modern turbine almost exclusive use of horizontal axis rotor. The goal of the approach presented here is to investigate a simplified method of blade design while maintaining acceptable accuracy in small wind turbine blade design.

No. of Blade (B)	Pitch angle (β)	Solidity (σ)	Electrical power, P_{rated}, W	AEP, kWh	V_{cut-in} (m/s)	C_{pmax}	λ at $C_{p\,max}$	C_{Qmax}
3	3	0.03	388	493	2.3	0.46	7	0.06

5	3	0.05	422	536	2.3	0.5	5	0.1
7	3	0.1	405	514	2.3	0.48	4	0.12

In above table represented blade result for number of blade 3, 5 & 7 respectively. Also, When number of blades is increased from 3 to 7, values of power coefficient increases up to 10%.The 3, 5 & 7 bladed rotor achieved value of Cp 0.46, 0.5 & 0.48 at the pitch angle of 0 and 3 degree, respectively whereas the Torque Coeff of 3, 5 and 7-bladed rotor achieved value of 0.06, 0.1, 0.12 at tip speed ratio 7, 5 & 4 respectively. It observed that the approximate 8% and 4% maximum annual energy production was obtained for blade number is equal to 5 as compared the blade number is equal to 3 and 7, and capacity factor is equal to be =0.145 for all cases. Hence optimum number of blade is equal to be 5

8. CONCLUSION:-

This research paper provides a complete picture of wind turbine blade design and shows the dominance of modern turbine almost exclusive use of horizontal axis rotor. The goal of the approach presented here is to investigate a simplified method of blade design while maintaining acceptable accuracy in small wind turbine blade design. It has been discussed about literature review with research work details of various authors and there major area and field of work with respect to small wind turbine. Which mentions various parameters like, rotor blade, constant chord and untwist blade, pitch angle, blade solidity, after survey of the various research paper it has been observed that very less work and analysis has taken place in the area of blade geometry (variable chord and twisted blade) and therefore the same field of work has been taken for the project thesis to improve rotor performance, reduce the cut- in wind speed and optimize blade geometry. Also, when number of blades is increased from 3 to 7, values of power coefficient increases up to 10%.

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